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**TECHNICAL REPORT ON  
PACIFIC 'SOFAR' VELOCITY  
CALIBRATION EXPERIMENT**

**Sponsored By The  
Advanced Research Projects Agency  
Project VELA UNIFORM**

**Submitted to  
Office of Naval Research  
Field Projects Branch  
Washington, D. C.  
Under Contract Nonr-4298(00)  
ARPA Order No. 210**

**DDC  
JUL 8 1961**

**GM DEFENSE RESEARCH LABORATORIES**

**SANTA BARBARA, CALIFORNIA**



**SEA OPERATIONS EXPERIMENT**



**Prepared by the  
General Motors Research Laboratories  
Warren, Michigan**

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**SEA OPERATIONS DEPARTMENT**

**TR65-28**

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**JUNE 1965**

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WITH THE GM DRL CLASSIFIED DOCUMENT SERIAL  
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## I. SUMMARY AND CONCLUSIONS

### 1.1 THE EXPERIMENT

During the summer of 1964 a SOFAR velocity measurement experiment was conducted by GM Defense Research Laboratories between Hawaii and the California coast and between Hawaii and certain islands in the North Central Pacific. Signals also were received and utilized for velocity computation from an independent, concurrent experiment in the Aleutians. GM DRL developed and used a deployable acoustic monitoring buoy station to record signals. Additional fixed acoustic installations were used on the coast of California and on the islands of Eniwetok and Midway. The charges for the GM DRL Oahu shots were M-3 demolition blocks, equivalent to a few pounds of TNT. These were electrically fired at the approximate depth of the SOFAR axis from USS ARIKARA (ATF 98). In the Aleutians, shots equivalent to about one ton of TNT were fired at shallow depth by the RV SEA SCOPE, and 248-lb depth charges to be located acoustically were dropped by a Navy patrol aircraft.

### 1.2 THE OBJECTIVES

The principal objective of the experiment was to measure the average SOFAR velocity between widely spaced termini and to determine the fluctuations in this measurement. A secondary objective was to determine whether, over a period of five days, coherent temporal variations could be observed and, if so, to correlate them with possible causes. A knowledge of the SOFAR velocity and its fluctuations is required for acoustical source-location systems. (T phase sources are now being located acoustically, and potential systems to locate the sources of nuclear events by means of their underwater acoustic signals are the subject of current research). In a program for computing acoustical source locations, the mean acoustic propagation velocity is an important parameter; also important are the fluctuations of the acoustic propagation velocity. These fluctuations, which are a measure of the uncertainty in our knowledge of the propagation velocity, largely determine the obtainable precision in the location of source events.

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### 1.3 RESULTS

The average propagation velocity, computed and observed for various paths, together with fluctuations, are indicated below:

| Source Location | Receiver Location                          | Propagation Velocity (meters per second) |                        |          |                    |
|-----------------|--|--|------------------------|----------|--------------------|
|                 |  | Computed                                 | Number of Observations | Observed | Standard Deviation |
| Oahu            | San Miguel Is. Calif. coast (buoy station) | 1480.87                                  | 50                     | 1479.27  | 0.85               |
| Aleutian Trench | Same                                       | 1472.87                                  | 7                      | 1468.55  | 0.51               |
| Oahu            | Midway                                     | 1482.09                                  | 22                     | 1480.66  | 0.31               |
| Oahu            | Eniwetok                                   | 1472.87                                  | 20                     | 1482.69  | 0.51               |

The predominant part of the standard deviations quoted above, particularly in the first two paths, must be attributed to experimental effects and not to the fluctuations of the properties of the medium. It was not possible to correlate the observed fluctuations in average propagation velocity with any geophysical effects; nor was it possible over a five day period to determine unambiguously any trends in the average propagation velocity. Hence, these fluctuations must be considered random and attributed to the statistical nature of the generation, propagation, and measurement process.

A source location program was developed and applied in a real problem of locating the sources of signals from the 248-lb, air-dropped Aleutian charges. An rms ensemble residual of about 4 km was observed; the mean contradiction between GM DRL acoustic positioning and the navigational information from the aircraft was 11.9 km.

### 1.4 CONCLUSIONS

If the standard deviations reported above are combined with other data, the minimum uncertainty in range determination may be calculated for various propagation paths:

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| Paths                   | Effective<br>Std. Dev.<br>(m/sec) | $\frac{\sigma}{\langle c \rangle}$ | Average<br>Range<br>(km) | Range<br>Uncertainty<br>(km) |
|-------------------------|-----------------------------------|------------------------------------|--------------------------|------------------------------|
| Oahu to West Coast      | 0.775                             | $5.238 \times 10^{-4}$             | 3884                     | 2.03                         |
| Aleutians to West Coast | 0.955                             | $6.495 \times 10^{-4}$             | 4295                     | 2.79                         |
| Oahu to Midway          | 0.310                             | $2.094 \times 10^{-4}$             | 2151                     | 0.45                         |
| Oahu to Eniwetok        | 0.350                             | $2.361 \times 10^{-4}$             | 4344                     | 0.47                         |

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## II. INTRODUCTION

### 2.1 STATEMENT OF PROBLEM

The detection, classification, and location of underground or underwater nuclear explosions must utilize a portion of the energy of the detonation, generally after the energy has been propagated long distances (from the source of the blast to the location of the detection devices). Most systems for these purposes are seismic, i. e., they measure energy that has traveled through the earth's lithological material. Recently, however, there has been an increase in attention to underwater acoustical methods of detection. For land-based blasts these methods depend on the T phase, a low-frequency, underwater acoustic signal seismically generated.<sup>(1, 2, 3)\*</sup> For in-water blasts the acoustical energy is generated directly by the blast mechanism and propagated long distances. One distinctive characteristic of the in-water blast is that it sometimes produces a pronounced, closely-spaced line structure that is not seen in T phases. Source localization depends on the stability of the ocean as a long-range propagation medium. The two principal objectives of this experiment were (1) to obtain a measurement of the average propagation velocity in the Northeast Pacific over various long path lengths based on a statistically significant number of readings and (2) a measurement of the stability of this velocity over a period of several days.

### 2.2 STATEMENT OF WORK

The contract statement of work provided for the following:

" (5) conduct field experiments related to the generation, propagation, and detection of T phase signals,

(6) at designated stations the Contractor will monitor the 1964  
VELA UNIFORM Aleutian Shot Series . . . . . ,

\* Raised numbers in parentheses refer to list of references on page 51.

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- (7) provide technical personnel at the stations for the purpose of making the recordings; and
- (8) reduce the data to tubular form; and
- (9) perform special analysis on selected signals; and
- (10) provide a copy or the original on magnetic tape of the recordings taken."

### 2.3 CONCEPT OF THE EXPERIMENT

The SOFAR calibration experiment was an attempt to measure properties of the ocean. Shots were to be detonated from a firing vessel near Oahu and received at stations along the California coast and in the North Central Pacific. To remove the masking effect of experimental error it was necessary to impose very precise control on both the generation and reception of the acoustic signals – that is, a precise knowledge of both the time and location of the sound sources was demanded. Since a statistically significant sample size was sought, about 100 shots were planned. Economy and the required precise timing of the shots prompted the use of Navy M-3 demolition blocks (Composition C), electrically detonated and timed. For the firing system it was necessary to design and construct an electrical firing box with special timing terminals and to procure special seismic blasting caps, pressure rated for 1200 psi. The requirement for precise knowledge of the shot position meant that the firing vessel had to have a sophisticated navigation control system – this was Hydrodist, an electronic distance-measuring system, comprised of two shipboard units and two shore stations located accurately with respect to triangulation points.

A self-recording acoustic buoy system was developed and used in the experiment. This system, consisting of a submerged shallow buoy suspending a deep hydrophone on its mooring line at the SOFAR axis, recorded signals for about two weeks. The system served two purposes: (1) it backed up and supplemented data from the fixed stations, and (2) it tested the concept of a deployable recording buoy which could be implanted in strategically important but inhospitable geographic areas.

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## 2.4 CHRONOLOGY

The significant events in the conduct of this experiment are listed chronologically below (all dates 1964).

|      |  |
|------|--|
| 4/20 | Commenced ordering hardware for field experiment   |
| 5/18 | Commenced work as per task statement   |
| 6/22 | Conducted site reconnaissance  |
| 6/26 | Liaison established with: COMSERVPAC, CO ARIKARA,<br>US ARMY HAWAII, University of Hawaii, NAD OAHU,<br>Eaves & Meredith   |
| 7/1  | Design firm on buoy and explosive source systems   |
| 7/8  | Pressure tested buoy (MS 15-64)  |
| 7/14 | Arrangements completed with OU/CWSF for manning site   |
| 7/20 | Conducted first major system sea tests (MS 16-64)  |
| 7/22 | Tested buoy installation, ship positioning with Hydrodist,<br>explosive rigging and firing (recovery of buoy unsuccessful) |
| 7/23 | Recovered buoy using support vessel to assist SWAN   |
| 7/26 | Naval Facility reconnaissance  |
| 8/7  |  |
| 8/10 | Conducted shallow water release tests (MS 19-64)   |
| 8/11 |  |
| 8/17 | Coordinated arrangements with NEL  |
| 8/19 | Group A NavFac field party on station  |
| 8/21 | First NavFac contingent recalled temporarily   |
| 8/25 | Hawaii field party departs for exercise  |
| 8/27 | Deployed buoy system for recording of firing runs  |
| 8/31 | ARIKARA at sea   |
|      | Group B NavFac field party on station  |
| 9/1  | GM shots commence  |
| 9/2  | Alaskan shots commence   |
| 9/5  | GM shots complete  |
|      | ARIKARA returns to port  |
| 9/6  | Group A NavFac field party returns GM DRL  |
| 9/9  | Buoy recovered (MS 26-64)  |
|      | Hawaii field crew returns  |
| 9/21 | Alaskan shots complete   |
| 9/21 | Group B NavFac field party returns   |

### III. ACOUSTICAL SOURCE SYSTEM

#### 3.1 GENERAL

Sources of the timed signals had to be both safe and inexpensive, and information about the position and time of the source signal had to be accurate. Safety was a concern because the decision had been made to use available explosives as sound sources. Expense was important because of the large number of shots to be fired.

Based upon all of these considerations, the sound source system was designed to use electrically-fired standard Navy M-3 demolition blocks. The explosive is Composition C, a stable plastic material capable of taking the 1200 psi of the firing depth.<sup>(1)</sup> Also capable of withstanding the high ambient pressure were the special seismic blasting caps, manufactured by DuPont and designated "SSS."

#### 3.2 ACCURACY LIMITS

The overall design of the experiment dictated the precise knowledge required of charge location and detonation time. Variations in transit time due to uncertainties in the position of the charge and time of firing were to be kept below the point where they could mask the observable fluctuations in transit time caused by oceanic inhomogeneities. A limit to precision is set by the characteristics of the received signal itself. The time of the SOFAR axis arrival, indicated by an abrupt fall in signal level, is measurable to about 100 ms. If uncertainties in source position and time were each to be held to about 20% of the signal uncertainty, then they should not measurably widen the statistical spread in the results. Hence, source time uncertainty was to be held to 20 ms, and position uncertainty to 100 feet. Both of these were attainable.

The time measurement required a firing circuit that would record at the same time it fired the charge. The position uncertainty requirement led to precise electronic equipment to locate the firing ship. An electronic distance-measurement

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system known as "Hydrodist" was employed; this navigation system requires two accurately determined land-based stations from which precision distance measurements can be made to the ship. With a specially prepared grid chart, the geographical position of the ship can be determined to uncertainties of less than 10 feet in ranges up to 14 miles from the shore stations.

The charges were suspended on an electric cable with a 50-lb weight at the end to reduce wire angle at the moment of firing; 2,400 feet of cable was streamed. Correction of horizontal and vertical displacement depended on wire angle at the ship; the amount of change was arbitrarily fixed at one-half of the straight geometric correction. This procedure is based on the practice of oceanographers in correcting Nansen bottle cast geometry:

$$\Delta X = 1/2 L_w \sin \theta \quad \text{horizontal correction}$$

$$\Delta Z = L_w (1 - 1/2 \cos \theta) \quad \text{vertical correction}$$

where  $L_w$  = length of wire

$\theta$  = wire angle at surface. i.e., angle  
between vertical and tangent to wire.

### 3.3 FIRING CIRCUIT

The firing box was designed to operate from the ship's 120-vdc system. Safety interlocks of banana-plug jumpers that were part of the firing circuit prevented the firing circuit from closing accidentally. (If a technician keeps an interlock with him while working on the firing circuit, the circuit can be closed only with his knowledge and concurrence.) The firing box also provided a voltage tap on either side of a 1-ohm resistor to measure the firing current. Leads from this point went to one channel of a two-channel Sanborn recorder to indicate the instant of switch closure; the other channel received time marks from radio station WWV. The firing circuit diagram is shown in Figure 1, and the firing box is illustrated in Figure 2.

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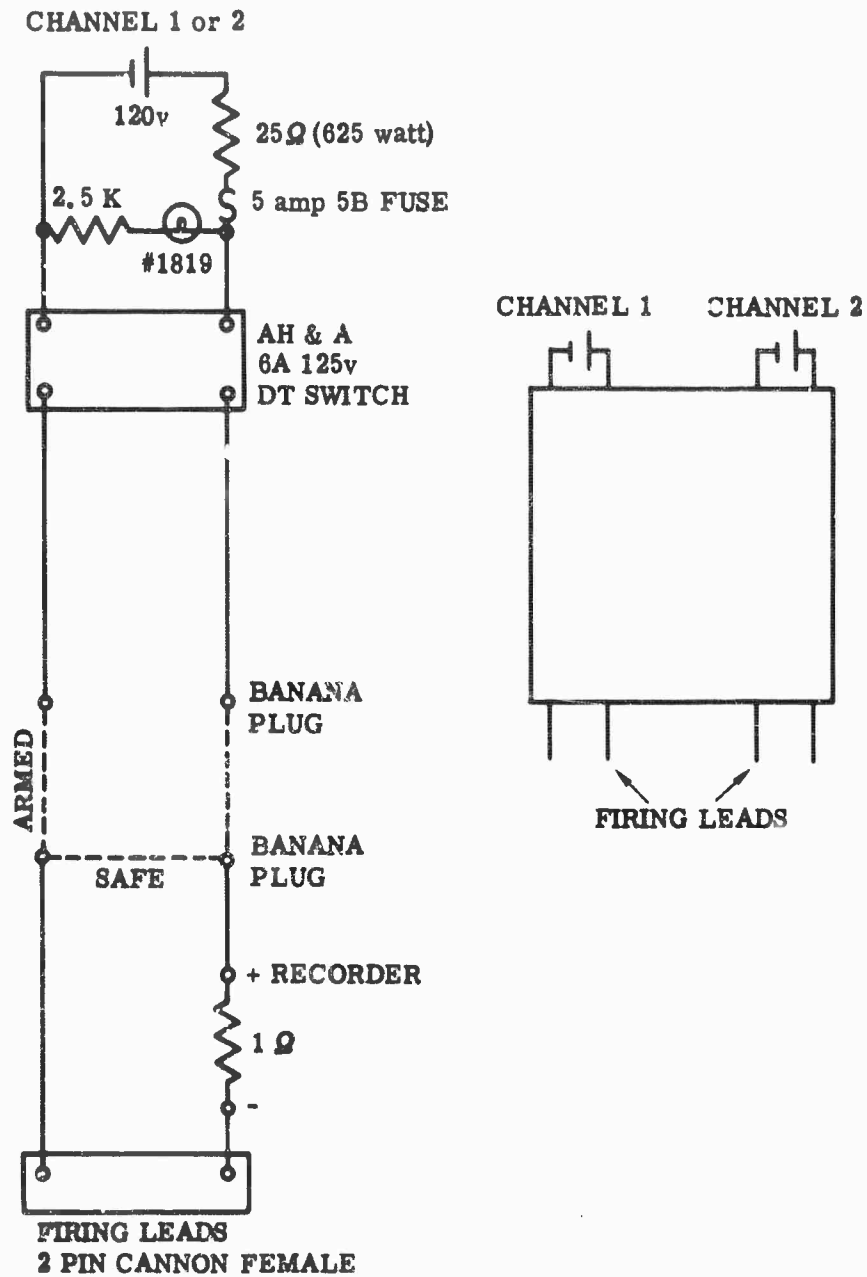


Figure 1 Firing Circuit Diagram

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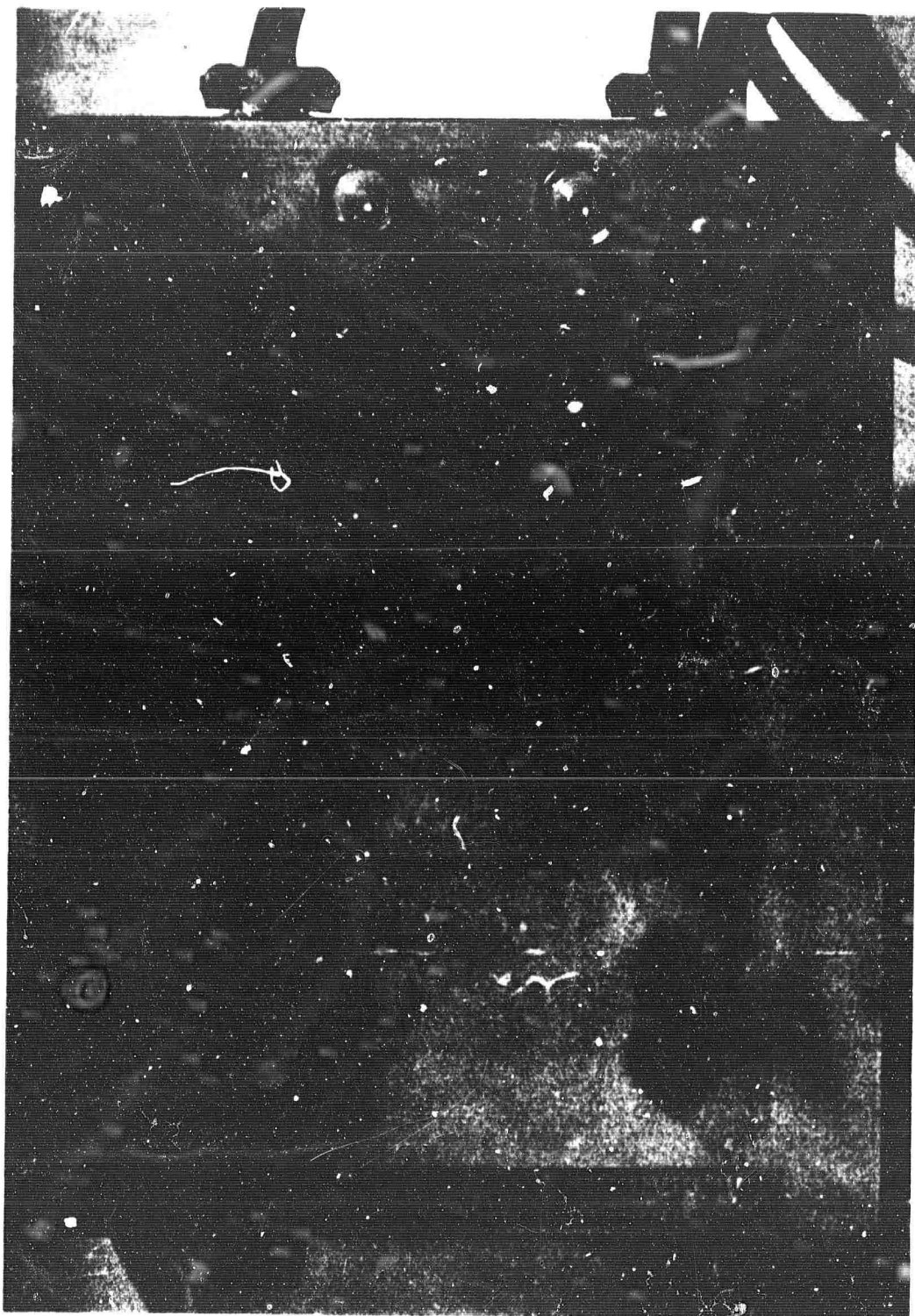


Figure 2 Firing Box

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## 3.4 SOURCE LEVELS

Source levels and spectra, computed from Weston,<sup>(4)</sup> were

$$P(t) = p_o e^{-t/t_o}$$

$$p_o = 2.16 \cdot 10^4 \left[ \frac{W^{1/3}}{R} \right]^{1.13} \text{ psi}$$

where  $W$  = charge weight in pounds

and  $R$  = distance from detonation center in feet

The time constant,  $t_o$  is found to be 0.15 ms when calculated for a 5-lb charge, a 10-ft horizontal displacement, and a depth of 2,400 feet.<sup>(4)</sup> The first bubble-pulse frequency will be 88.6 cps. From Cole,<sup>(5)</sup> the diameter of the first bubble will be 6.7 feet. In summary, the signal from these charges is very sharp, with rapid decay, a high bubble pulse frequency, and a small bubble. The receiving electronics was designed to be sensitive in the frequency range of the first bubble-pulse frequency.

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#### IV. ACOUSTICAL RECORDING SYSTEM (BUOY)

##### 4.1 MECHANICAL SYSTEM

Figure 3 shows the configuration of the deployed acoustical recording buoy system. The hydrophone is located in the vicinity of the SOFAR axis, and the spherical buoy containing recording instruments and batteries is located about 100 feet below the surface. Buoyancy of the submerged buoy provides tension to keep the system vertical and taut, conditions necessary for minimum horizontal excursion of the hydrophone. The clump anchor connects by means of a 3/8-in., 1 x 19 steel wire rope (IWRC\*) to the hydrophone/release assembly, which in turn connects to the submerged buoy via a 3/8-in., 7-conductor, double-helical, armored well-logging cable. The submerged buoy ties to a surface marker through a 1-in. Dacron line containing three electrical conductors, one in each strand. The release mechanism is controlled by a pre-set timer which discharges an explosive nut, dropping the eye-bolt in the lower mooring and freeing the rest of the system to surface under the upward pull of the submerged buoy. The anchor and mooring cable are not recovered. If the timing mechanism fails, or if premature recovery is desired, the explosive nut may be fired from the surface via one of the electrical conductors in the Dacron line. The other two conductors permit monitoring of the hydrophone.

The water depth at the implantment site was about 4,200 feet, and the SOFAR axis was found at about 2,400 feet. These dimensions required 1,800 feet of 1 x 19 mooring cable and 2,300 feet of well-logging cable. The 60-inch-diameter submerged buoy, weighing 386 pounds, produced a net positive buoyancy of about 2,415 pounds when loaded with electronics and batteries. The anchor, consisting of nine discs and a nose cone, weighed about 5,300 pounds in water. Since the submerged buoy supported a suspended weight of 1,210 pounds, a net tension of 1,205 pounds remained in the mooring at the anchor.

---

\* Independent Wound Rosin Core

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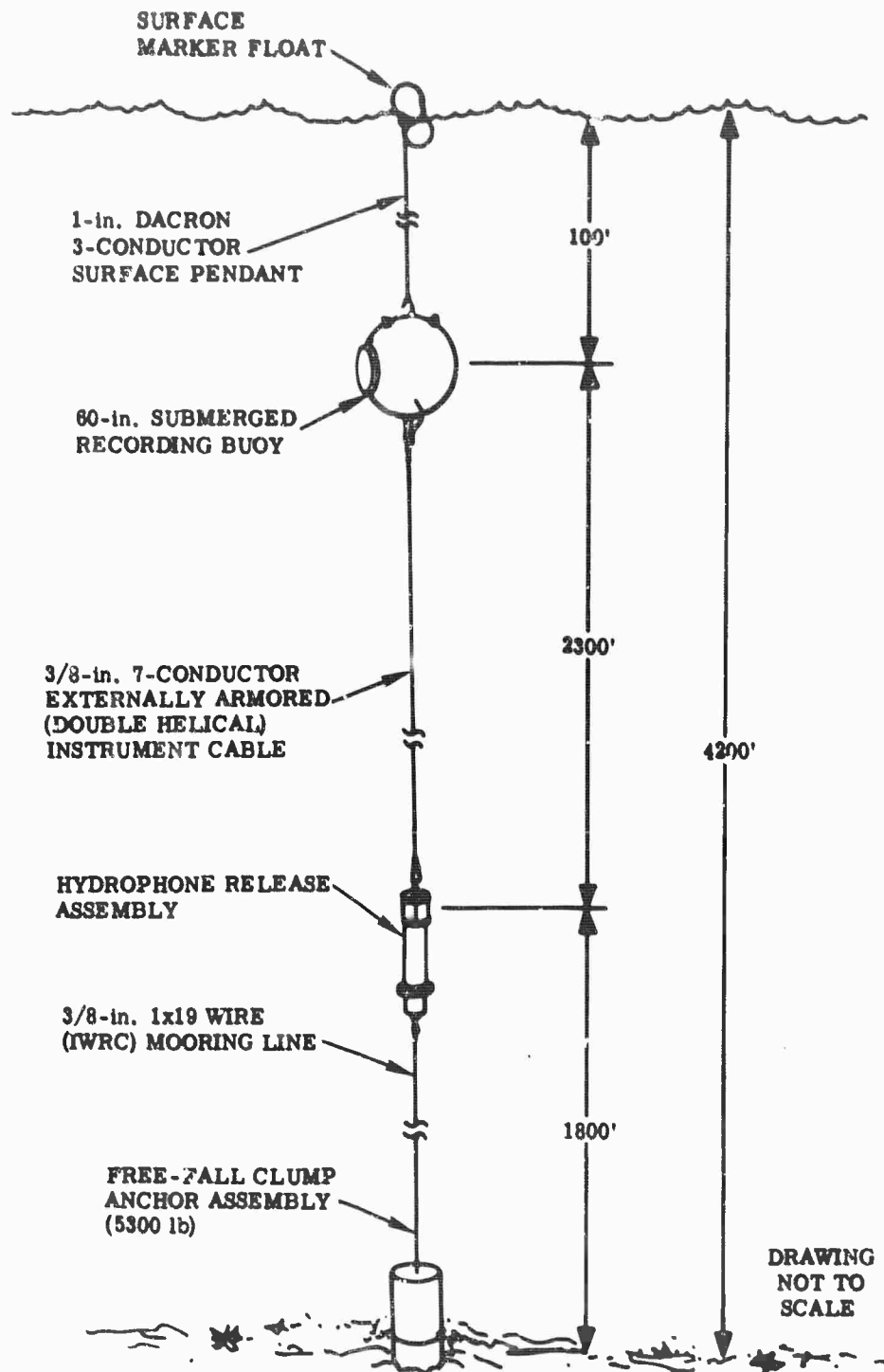


Figure 3 Acoustic Recording Buoy System Deployed

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The hydrophone, a  $\text{BaTiO}_3$  ceramic cylinder resonant at 28 kc with a calculated sensitivity of about -96 dbv per  $\mu\text{bar}$  and a capacitance of 0.0182  $\mu\text{f}$ , is shown in Figure 4. The hydrophone/release assembly housing is shown in Figure 5. The spherical buoy, in position to be laid from the afterdeck of SWAN, is shown in Figure 6.

#### 4.2 ELECTRONIC SYSTEM

Figure 7 is a block diagram of the electronic system. The hydrophone drives a 40-db preamplifier which in turn drives the cable to the submerged instrument buoy. The frequency band at the output of the preamplifier is designed to lie between 50 cps and 500 cps, the lower cutoff being above the high-level natural T phase noise, and the upper cutoff above expected signal frequencies.

At the submerged buoy the signal from the preamplifier is amplified further, and the detected output drives an optical galvanometer which marks light-sensitive paper carried on the drum of a helical recorder. The recorder advances at the rate of one turn every 15 minutes; at the end of 12 hours, on command from a crystal-controlled timer, the drum re-sets itself and advances its chart paper. Enough paper is carried for 15 days of continuous recording. The crystal-controlled timer also drives a separate optical galvanometer which places minute and hour marks on the record.

Figures 8 and 9 show circuit schematics of the hydrophone preamplifier and the buoy amplifier.

#### 4.3 INSTALLATION AND RECOVERY

Implantment of this single-taut-line buoy system utilizes the free-fall, baled-anchor technique developed at GM DRL. This procedure permits installation in a precise geographic spot, precludes the lengthy handling of heavy, pendulous weights, and may be accomplished smartly in very rough seas.

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RESONANT FREQUENCY 28 KC  
CALCULATED SENSITIVITY -96 dbv/ $\mu$ b  
CAPACITANCE 0.0182  $\mu$ f  
PRESSURE CAPABILITY >2000 psi

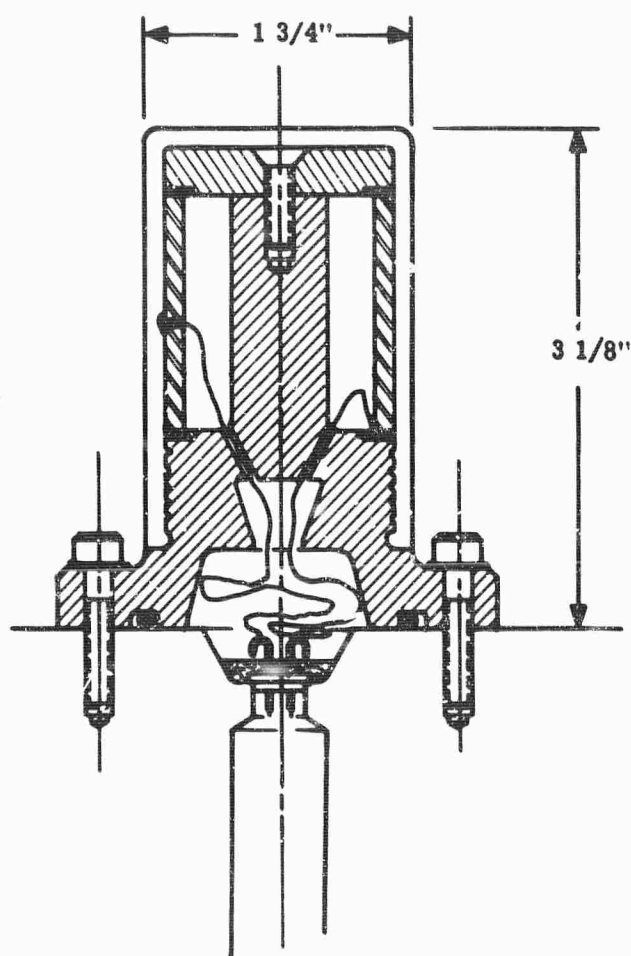


Figure 4 Hydrophone Assembly

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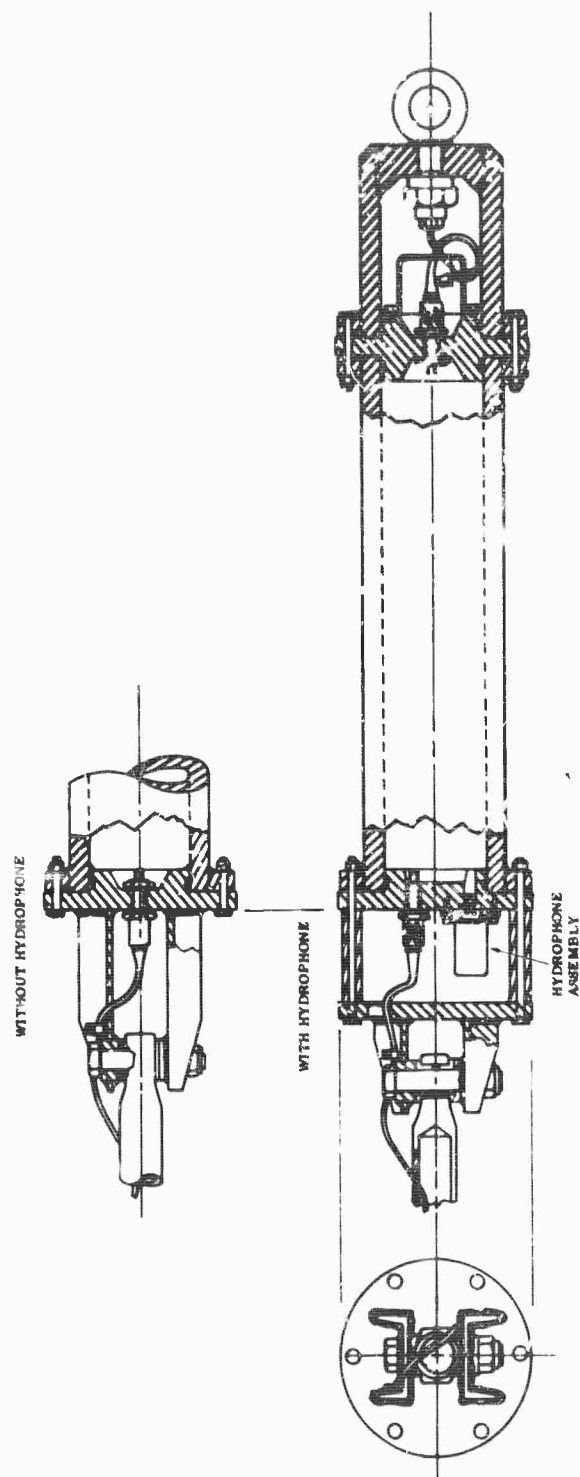


Figure 5 Hydrophone/Release Housing Assembly

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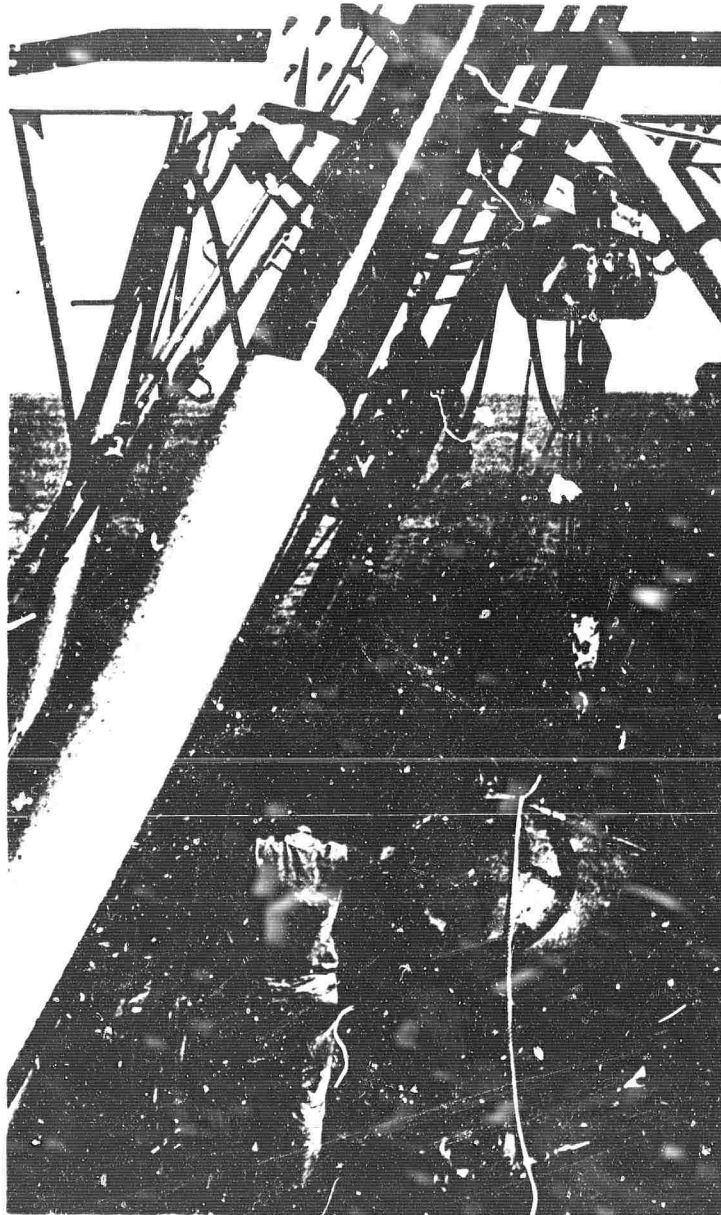


Figure 6 Submersible Instrument Buoy Aboard R/V SWAN

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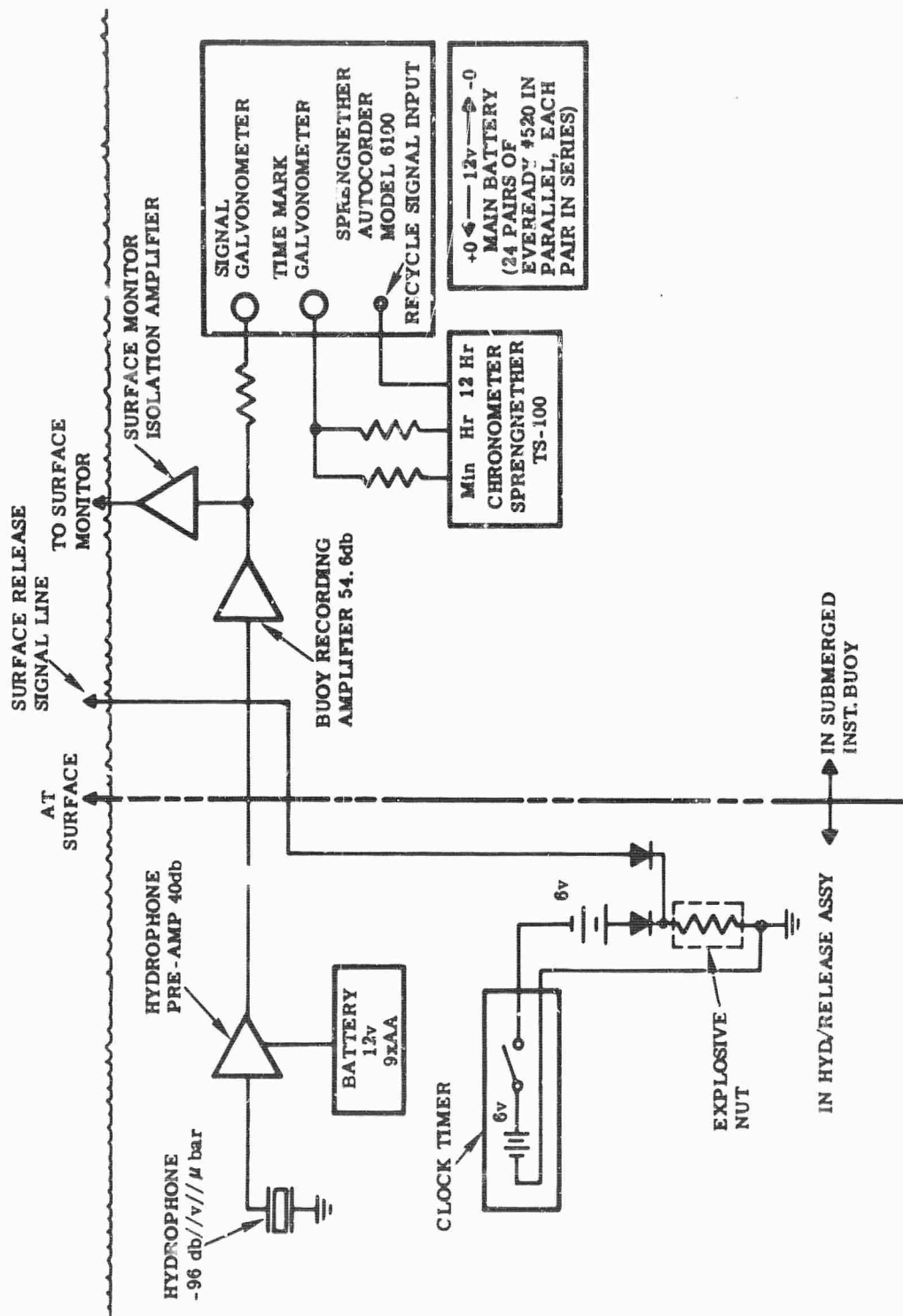


Figure 7 Electronic System Block Diagram

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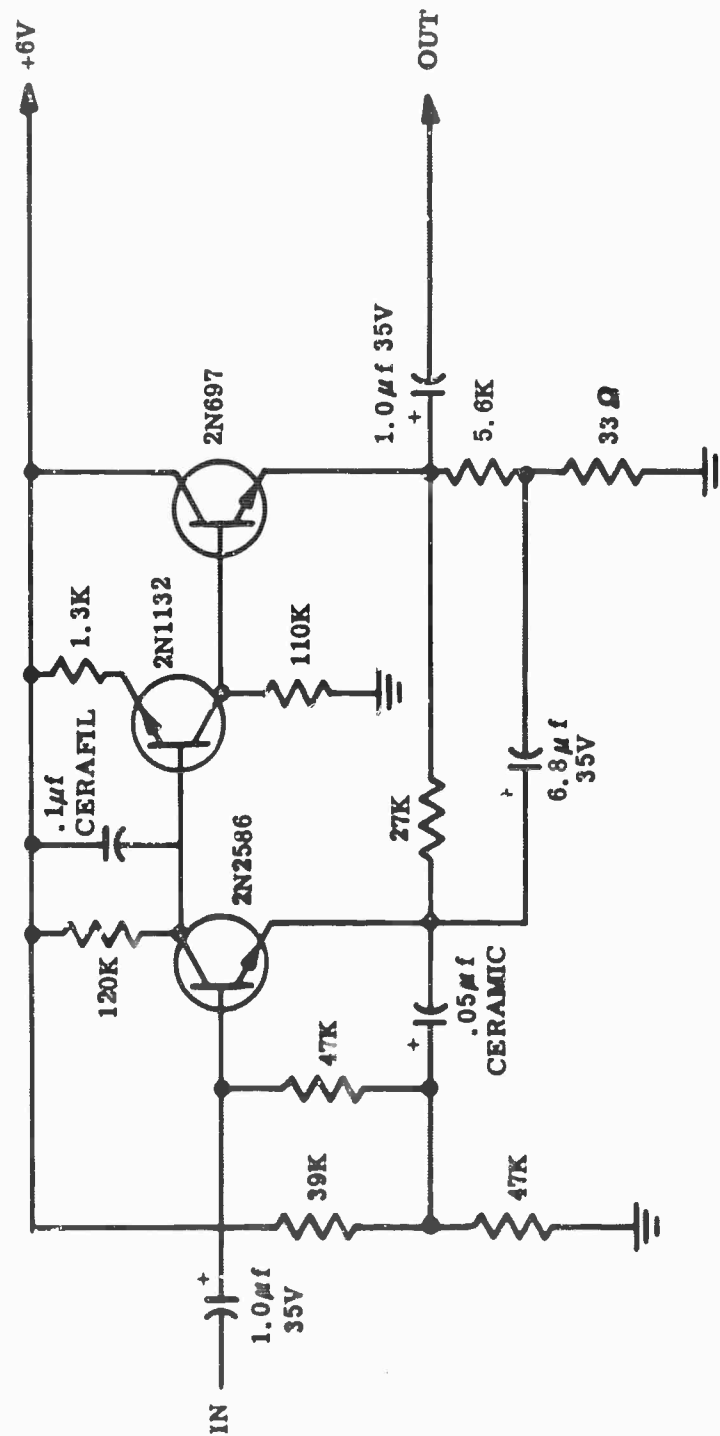


Figure 8 Hydrophone Preamplifier Circuit Schematic

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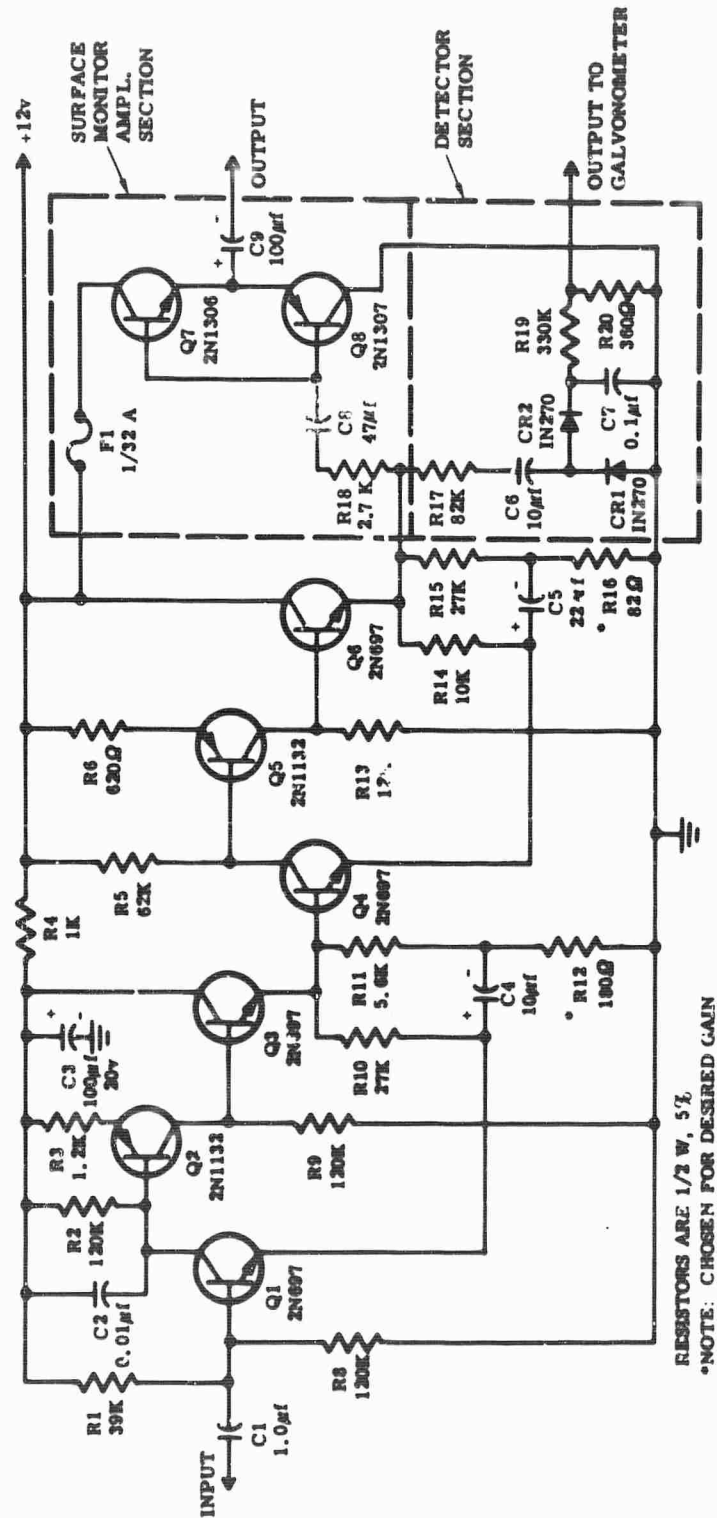


Figure 9 Recording Electronic Circuit Schematic

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Figure 10 illustrates the installation sequence. First into the sea goes the safety float which prevents loss of the system in case of trouble during implantment; the float is recovered after a satisfactory installation. Next to be streamed is the Dacron surface pennant which is supported along its length by plastic pneumatic floats. Then the spherical instrument buoy goes over. At this point the buoy is floating; later it will be carried down by the anchor. Then with the ship proceeding at about one knot to keep the buoys separated and tension in the lines, the well-logging cable is streamed until it is payed out. The end of the cable attaches to the upper end of the hydrophone/release assembly, which is lashed to the transom and ready to be released. One end of the 1 x 19 mooring cable attaches to the underside of the hydrophone/release assembly, and the other to the bale on the anchor assembly, which is rigged outboard ready to drop. The mooring line is pre-cut to the known water depth at the installation site. Navigation of the ship at the point of drop must be very precise, especially if the bottom is uneven or steeply sloping. During this installation by the SWAN, the Hydrodist electronic survey instruments aboard ship were used in conjunction with associated instruments at shore stations of known position. When the ship is over the precise geographical point and the sight in the instrument cable is correct, the anchor is dropped. It proceeds straight down, paying out wire as it goes. The hydrophone/release assembly is then cast overboard, thus freeing the entire system from the installing ship. When the mooring wire is out of the bale, the spherical buoy begins to move toward the drop point and then abruptly submerges. Finally, the anchor strikes bottom and the system is configured as shown in Figure 3, except for the safety float which is cast free and recovered. After the hydrophone is monitored for proper output, the surface pennant is taken up and secured to a plastic marker float. The taut-line acoustic monitoring system is now deployed and operating.

The helical recorder and timer are started before the installation, when initial time calibrations are inserted on the record using signals from radio station WWV. After recovery, a terminal time calibration will also be recorded. These time marks permit any long-term drift of the crystal-controlled oscillator to be measured so that timing corrections may be made in the data.

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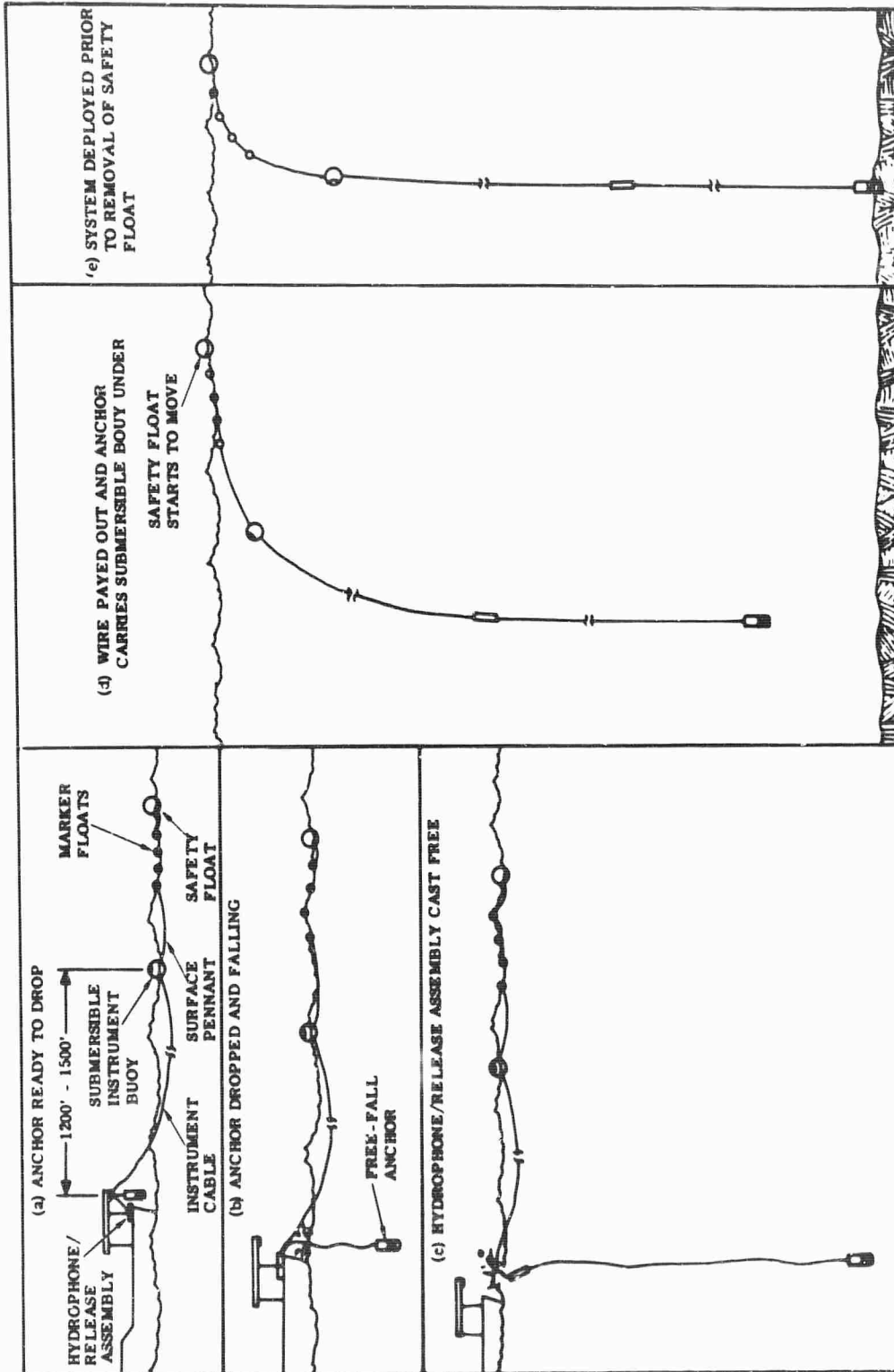


Figure 10 Acoustic Recording Buoy System Installation Sequence

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Normal recovery is effected by discharging the explosive nut mentioned in Section 4.1 through the circuitry described in Section 4.2. The actuating signal may come either from a pre-set timer in the hydrophone/release assembly or from a manually thrown switch on the surface. When the explosive nut discharges, the 1 x 19 mooring cable is released and the system from the hydrophone upward rises under the buoyant pull of the submerged buoy. Since the anchor and mooring are discarded, normal recovery does not involve the handling of large weights.

The two methods of recovery provide redundancy, but during the 1964 SWAN operation both methods failed, forcing recourse to emergency dragging. Recovery was finally effected by fine seamanship abetted by good fortune.

#### 4.4 RECORDS

A reproduction of a portion of the record recovered from the submerged instrument buoy is shown in Figure 11. This record is taken from the period of operation when GM DRL SOFAR shots were being fired hourly, and several of the signals from these shots are shown. This was also a period of low background ambient noise; the signal-to-noise ratio of these shots lies between 30 and 32 db. Duration of these signals ranges between 9 and 10 seconds; their typical sudden termination times the energy which has traveled along the SOFAR axis. Figure 12 shows the signal received from one of the TI Aleutian shots (No. 22). Since the recorder traces the detected output of the amplifier in the buoy within the dynamic range of the electronics, the area under the signal curve is related to the total energy received during the shot. The TI shot signal has a duration of about 19 seconds.

The acoustic monitoring buoy was installed on 27 August 1964 in the following location, about 6 miles south of San Miguel Island off the coast of Southern California:

Lat  $33^{\circ} 46' 15''$  N  
Long  $120^{\circ} 22' 30''$  W

The buoy was recovered on 9 September 1964.

TR65-28

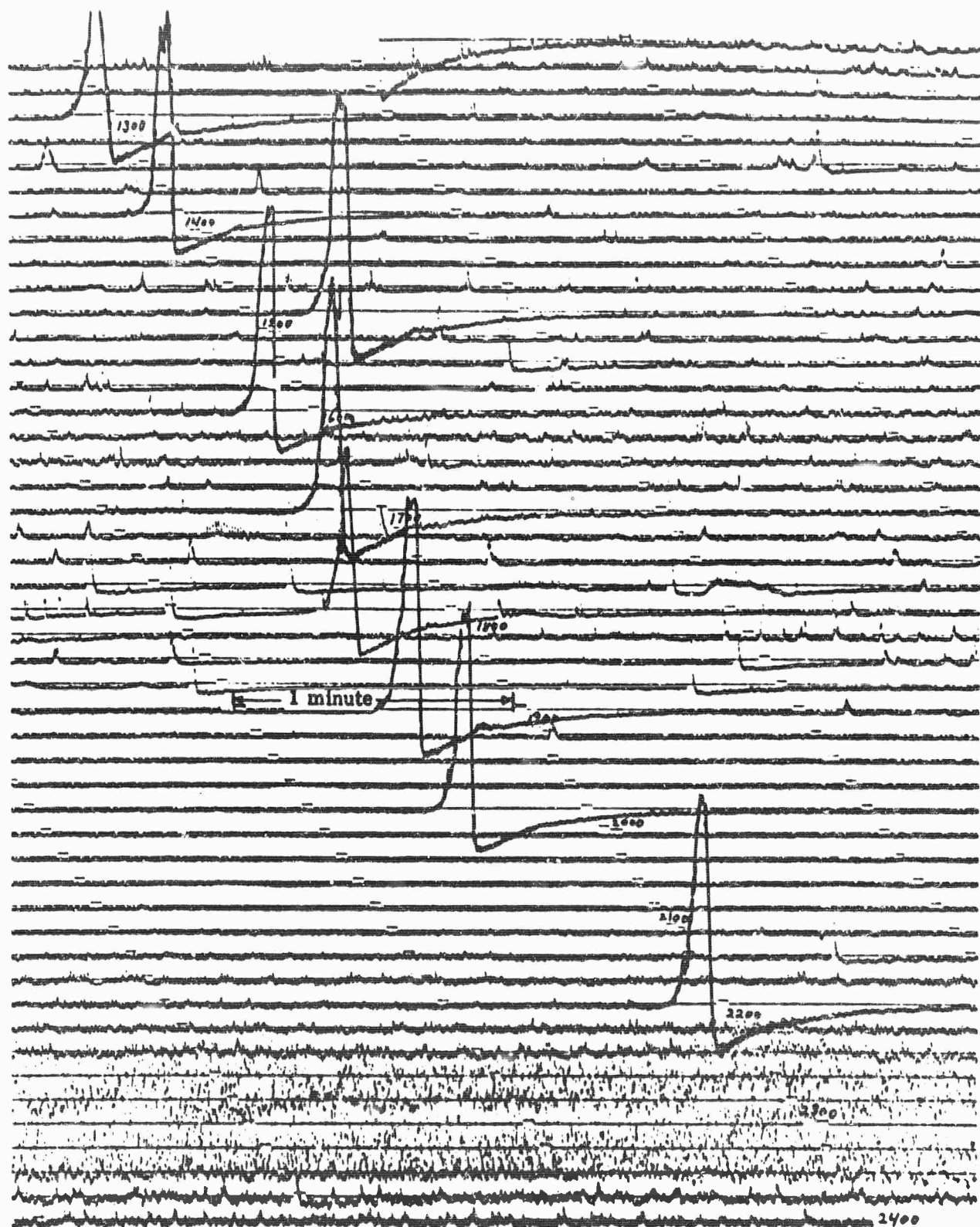


Figure 11 GM DRL SOFAR Signals Received by Acoustic Recording Buoy System

TR65-28

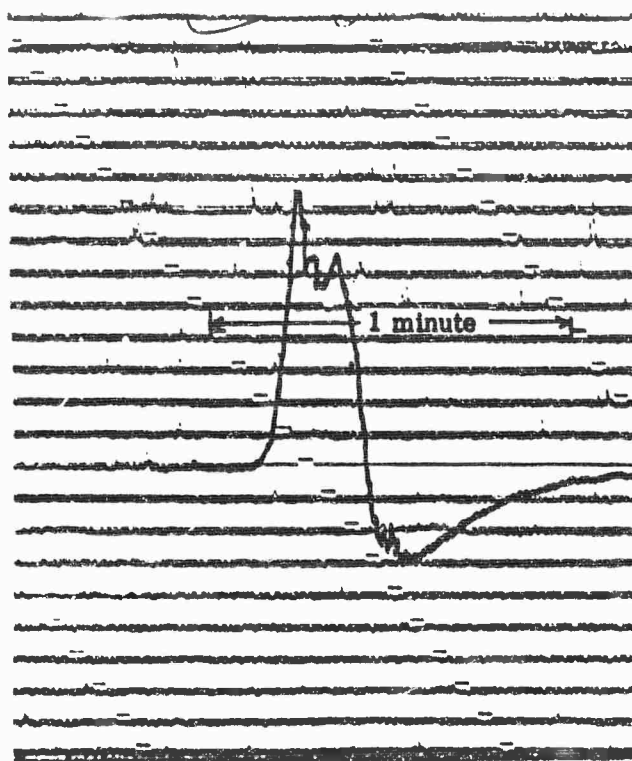


Figure 12 Signal from TI Aleutian 2376-lb Shot as  
Received by Acoustic Recording Buoy System

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## V. THE FIELD OPERATION

### 5.1 PARTICIPATING GROUPS

Two ships and two field parties participated directly in this shot program, and one ship and field party participated indirectly. A navy fleet tug, USS ARIKARA (ATF 98) (Fig. 13) served as firing vessel for the GM DRL Oahu SOFAR shots. Providing tactical support off the California coast, the GM Research Vessel SWAN (Fig. 14), in the course of several operations at sea, tested the charge firing system described in Section 3, and tested, installed, and recovered the acoustic recording buoy described in Section 4. One GM DRL field party coordinated the Hawaiian firing operation, with one section aboard ARIKARA and another operating the shore-based navigation stations. The other GM DRL field party recorded signals received at fixed hydrophone arrays on the West Coast. A third ship and field party, RV SEA SCOPE, a converted navy AM under the control of Texas Instruments, Inc. (TI), although operating in a completely separate and independent program was involved indirectly in the SOFAR calibration experiment. (See Reference 6 for a description of the TI program.) The GM DRL recording field party detected both the small GM Oahu SOFAR shots (5 - 18 lb) and the large TI Aleutian shots (2376 and 248 lb). Personnel of the Tsunami Project, Hawaii Institute of Geophysics, University of Hawaii, also provided data collection services. They tabulated arrival times of the GM DRL Oahu shots at two of the Pacific Missile Impact Location System (MILS) stations and forwarded data together with recorded magnetic tape to GM DRL.

### 5.2 PREPARATIONS

The success of such an operation requires preparation. Not only was there hardware to be designed, ordered, assembled, and tested, but coordination had to be established among the groups involved and services provided through existing military organizations. The Office of Naval Research provided the basic ship services. Details of schedule and logistics were then worked out directly with

TR65-28

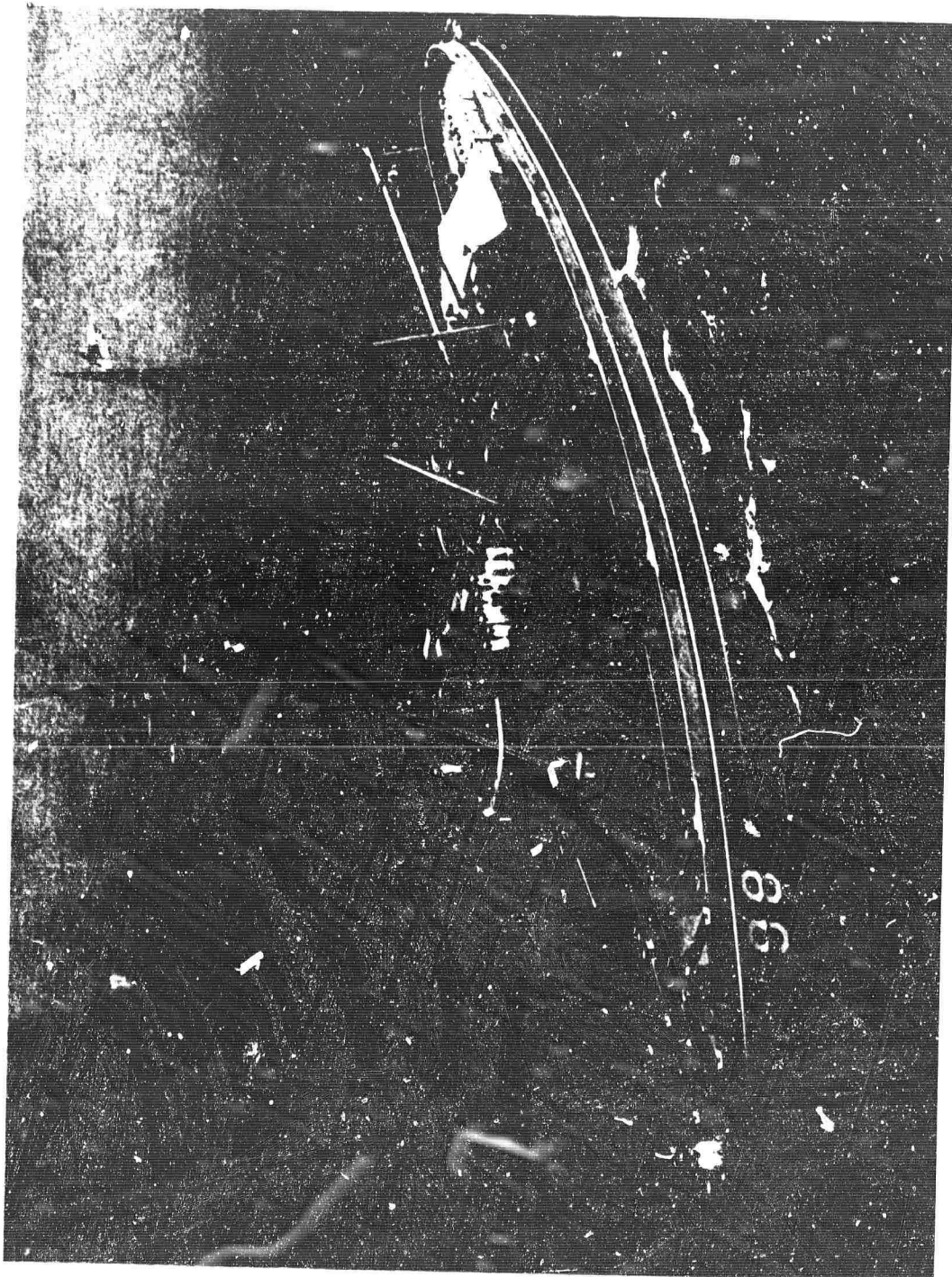


Figure 13 USS ARIKARA (ATF 98)

TR65-28

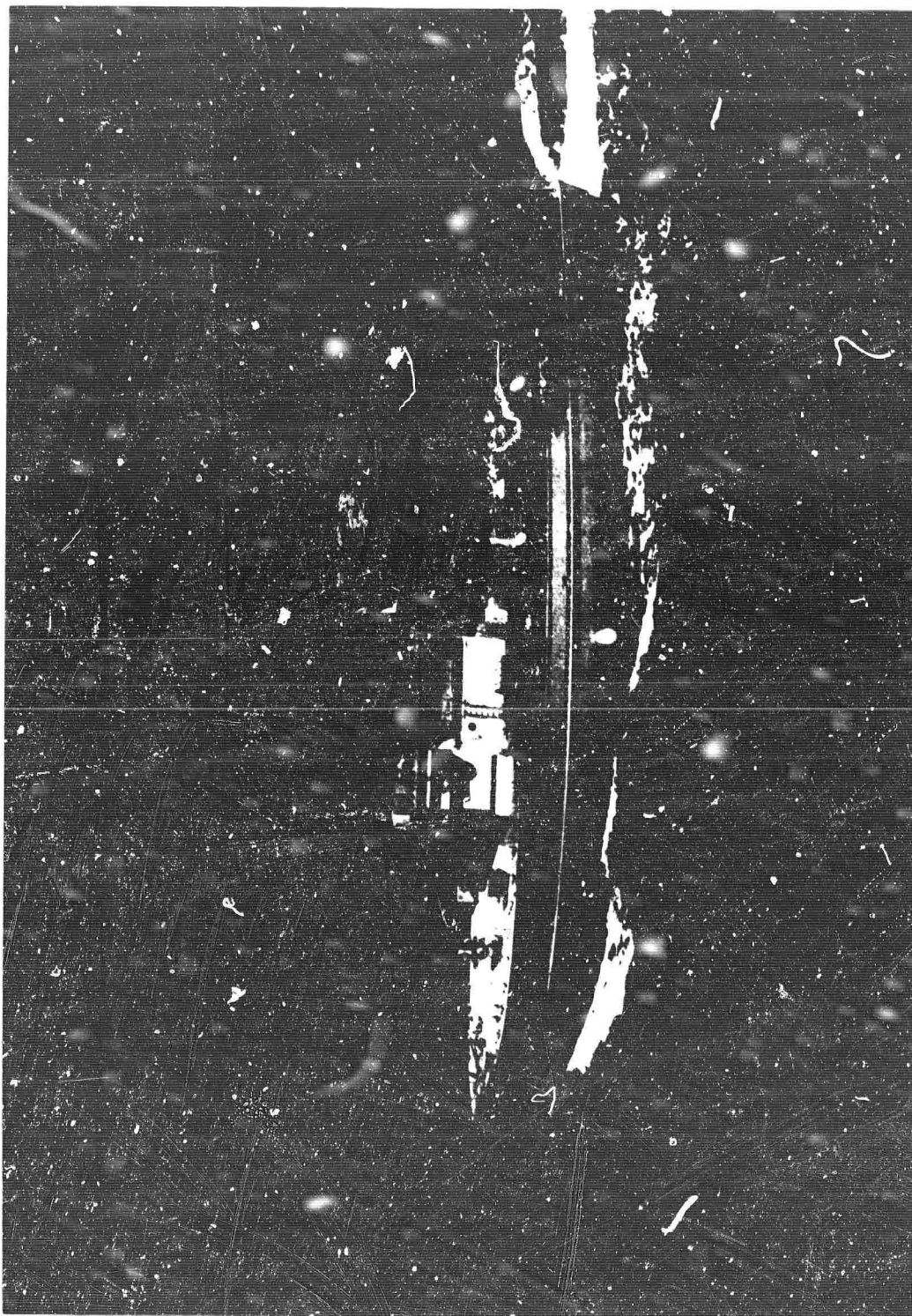


Figure 14 GM DRL Research Vessel SWAN

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Commander Service Force, Pacific Fleet, and the Commanding Officer of USS ARIKARA. To establish the shore navigation stations, permission had to be obtained through Headquarters, U S Army, Hawaii. The M-3 demolition blocks were provided by the Naval Ammunition Depots, one at Oahu and the other at Seal Beach, Calif., after an official letter request by the Office of Naval Research and telephone contact by GM DRL. Communication arrangements were made and information exchanged with TI and Air Force Cambridge Research Labs (AFCRL), the governmental control agency for the Aleutian shots. Contact was established also with the Navy Electronics Laboratory, San Diego, and their requirements were incorporated into the data recording method.

### 5.3 SCHEDULE AND PERFORMANCE

The GM Oahu SOFAR shots were to be fired once an hour for five days, which amounts to 120 detonations. Due to difficulties of one kind and another, only half of this number were actually fired. Figure 15 shows the actual firing times of these shots; note that good, around-the-clock coverage was provided with the exception of one hour when a series of misfires thwarted efforts.

The original schedule of the TI Aleutian shots and the actual performance are shown together in Figure 16.

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FIRING TIME FOR GM DRL SHOTS

LEGEND:  ~ GOOD SHOT  
 ~ FAILURE

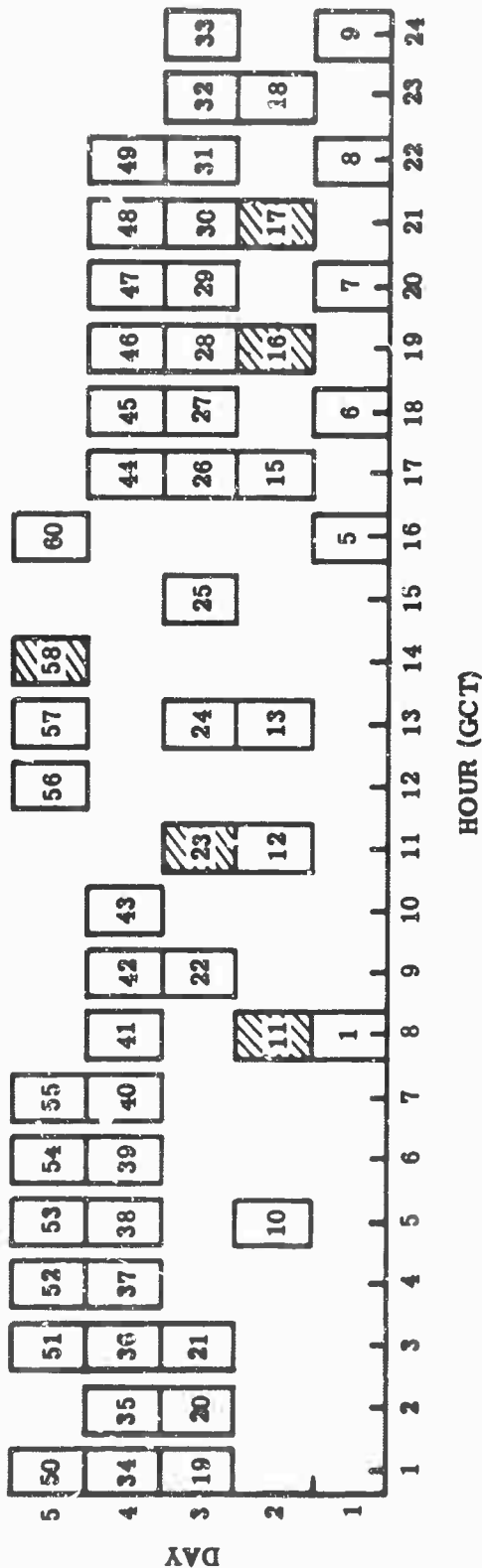


Figure 15 Diurnal Distribution of GM DRL SOFAR Shots

TR65-28

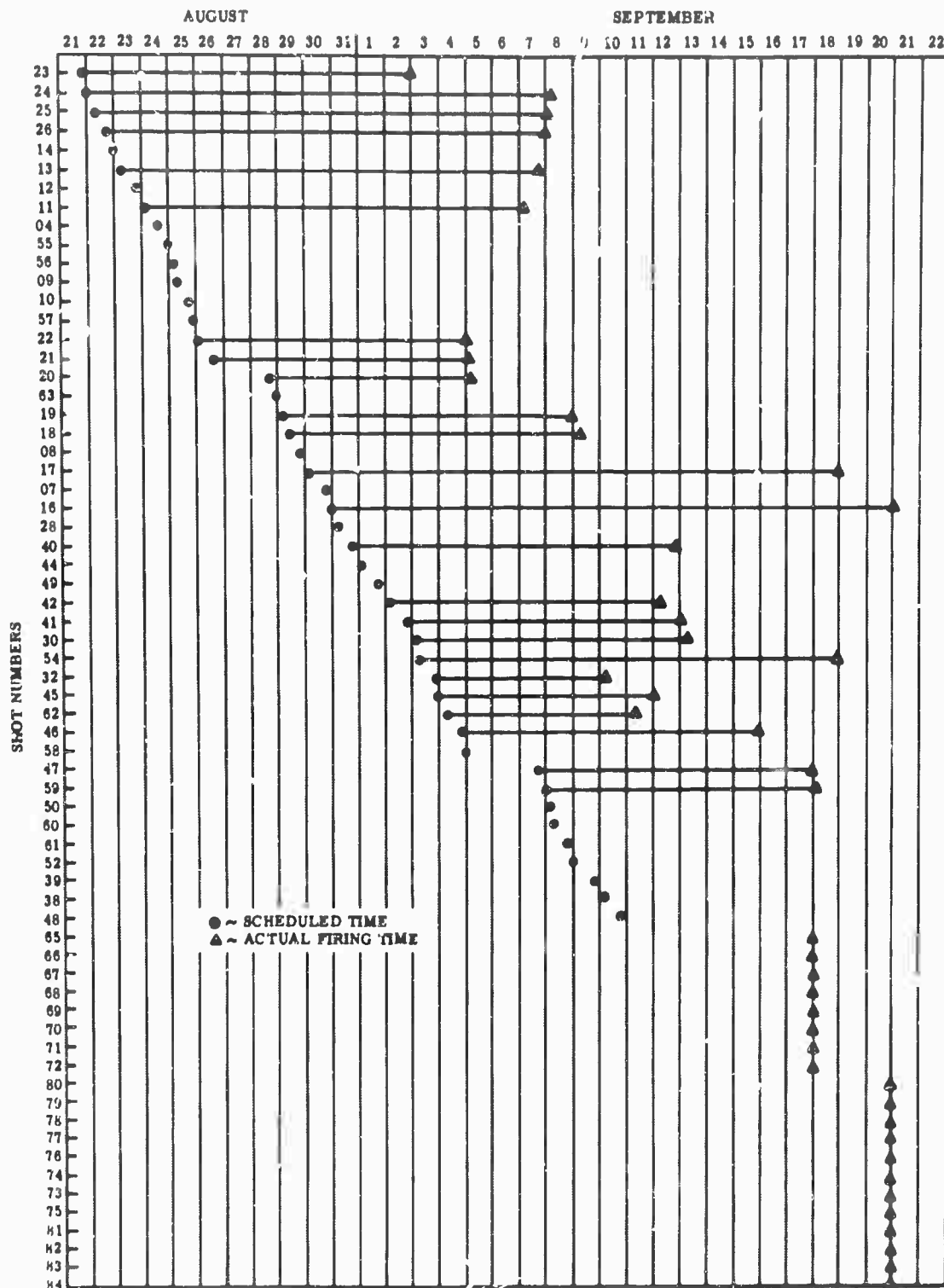


Figure 16 TI Aleutian Shots Scheduled and Actual Firing Times

## VI. DATA PROCESSING AND RESULTS

### 6.1 GENERAL

Appendices I and II contain data summaries of both the source events and recorded signal arrivals. Source data included detonation time and position, charge depth and weight, shot number and qualitative performance. Received-signal data included arrival times at two hydrophones, duration, signal level increase, background level, and amplifier gain. From source and arrival time information at a single receiver, the average propagation velocity was calculated for each shot; from this information at a group of receivers, source locations were computed; and from the information provided by a large number of arrivals, statistics relating to the stability of the SOFAR velocity were derived.

### 6.2 SOFAR VELOCITY COMPUTATIONS

#### Computer Program

Reduction of the observed source and received times was accomplished on an IBM 7040 digital computer in two principal stages. The first corresponds to the production of a source log deck. The second used this deck, plus received times, to compute average sound velocity.

#### Source Log Program

This first program included bringing together several separate logs kept by the charge detonation field party and performing several simple calculations to yield a clear source deck. The principal steps were as follows:

- a) Assembling of shot number, date, time, charge weight, and performance from logs
- b) Reduction of ship geodetic position from recorded Hydrodist readings to degrees, minutes and nearest second

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- c) Correction of ship's position to shot position from logs of wire payed out, wire angle, and true bearing. (In an attempt to compensate for wire catenary, the depth and horizontal range of the shot from the ship were calculated using an effective wire vertical angle of one-half the recorded value.)
- d) Printing and punching of all these quantities (the resulting source log is presented in Appendix I).

#### Sound Velocity Program

The second stage step included going from this source log deck and receiver log decks to average sound velocity (listings of the receiver decks are printed in Appendix II). The principal data given for each shot are station and shot numbers, date, arrival times at one to four hydrophones, shot trace amplitude, and system amplitude calibration (a listing of the sound velocity program is given in Appendix III). The principal events are:

- a) Input of alpha-numeric constants used by the program
- b) Reading and storing of source deck - information is referenced by shot number
- c) Conversion of geodetic source positions to geocentric coordinates in radians
- d) Reading of geodetic coordinates of centers of two receiving hydrophone arrays (in radians) and conversion to geocentric radians (in this program it was assumed that the first coordinate referred to the received times on channels 1 or 3 on the Sanborn trace, or both, and the second coordinate refers to channels 2 and 4).
- e) Reading one receiver card corresponding to a particular shot number

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- f) Computation of great-circle distance in radians from shot source location to receiver (uses a subroutine entitled GCD). This is converted to a distance in meters using the radius of the earth at the mean of the source and station latitudes (see U.S. Nautical Almanac on International Ellipsoid of reference).
- g) Computation of average velocity from this range and the difference between source and received times
- h) Taking of time differences in seconds between the times from channels 1 and 2 or 3 and 4. This relates to the shot's apparent bearing.
- i) Computation of approximate peak sound pressure level, according to the formula

$$\text{SPL} = R + B + A - G_0 - A_0 + M$$

where

R is the rise (in db) of the Sanborn trace

B is the background level or reference in db// 1 volt

A is the current system attenuator setting

 $G_0$  is the system gain at some previous time $A_0$  was the attenuator setting when  $G_0$  was measuredM is the hydrophone sensitivity in db// 1 volt/ $\mu$ bar

All the above quantities are read in for each shot, except M, which was assumed to be -80 db// 1 volt/microbar at 100 cps.

The sound levels thus computed should not be relied on for absolute value or for relations between stations due to our ignorance of absolute calibration. They are internally consistent, however.

- j) Outputting of all calculated data in printed form and punched-card form for statistical analysis
- k) Repetition of above steps e - j for each shot at a station
- l) Repetition of steps d - j for each receiving station

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The procedure above was repeated for each of the stations, but not for the buoy data. Since only one hydrophone channel was available and the recording medium different, the input format and calculations had slightly different forms from the above.

A listing of the computed sound velocities, time differences, and sound pressure levels is given in Appendix IV for the GM shots received at various stations and for some TI shots received at fixed installations.

### 6.3 SOFAR VELOCITY SUMMARY

Average sound velocity results, computed for the indicated termini points, are discussed below.

| Source      | Receiver               |
|-------------|------------------------|
| GM DRL Oahu | Recording Buoy Station |
|             | Midway MILS Station    |
|             | Eniwetok MILS Station  |
| TI Aleutian | Recording Buoy Station |

These time series data are plotted in Figures 17 through 20. Mean sound velocities for each pair of termini, together with standard deviations, are listed in Table I which also shows the calculated average sound velocity based on Johnson.<sup>(7)</sup>

Average expected sound velocity over a total distance  $D$ , where the theoretical propagation velocity is known in  $N$  piecewise increments and assumed to be constant over the distance interval  $D_j$ , is given by

$$\langle c \rangle = \frac{D}{\sum_{j=1}^N \frac{D_j}{c_j}} \quad (1)$$

where

$$D = \sum_{j=1}^N D_j \quad (2)$$

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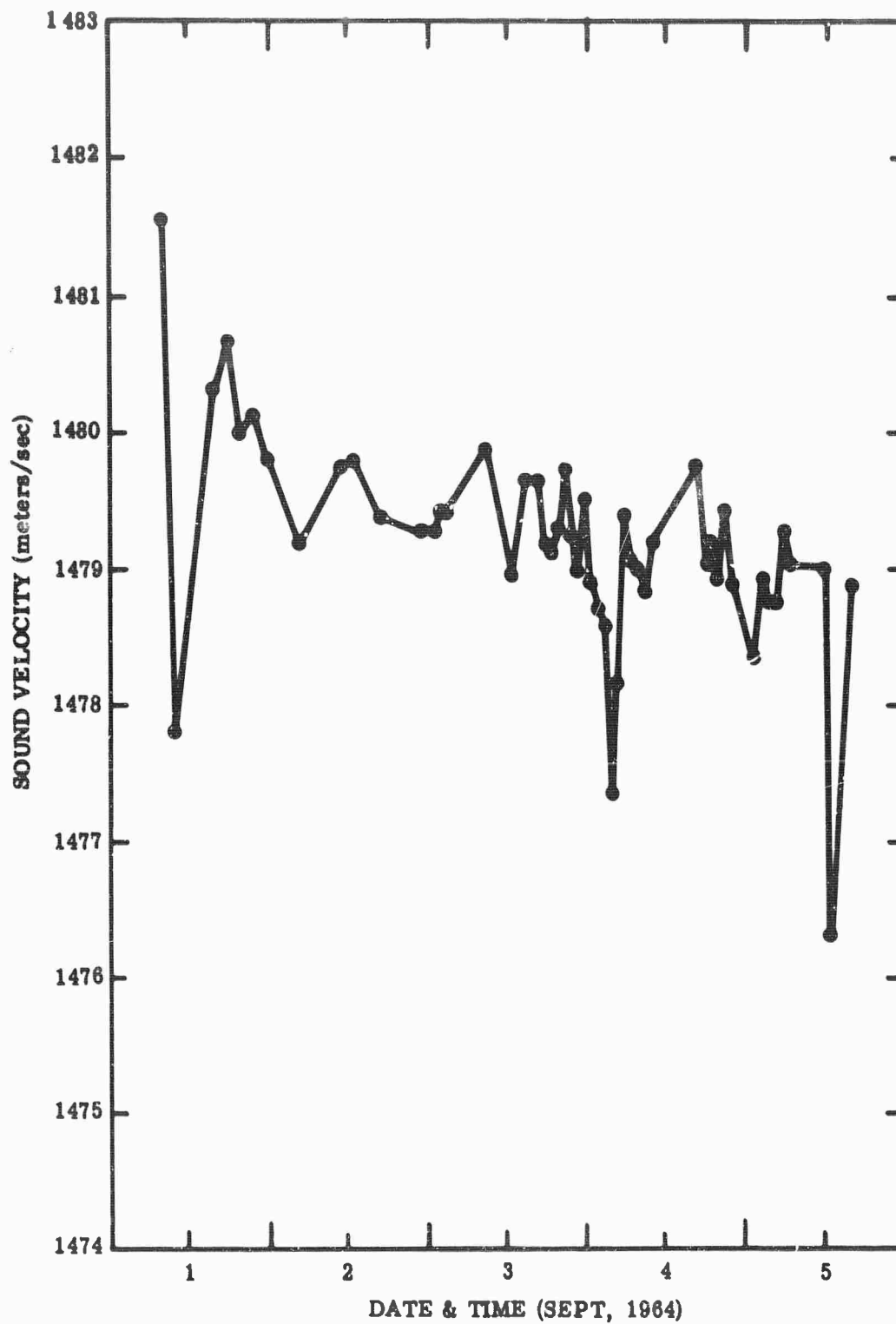


Figure 17 Average Sound Velocity GM DRL Oahu SOFAR Shots  
Received by Acoustic Recording Buoy Station

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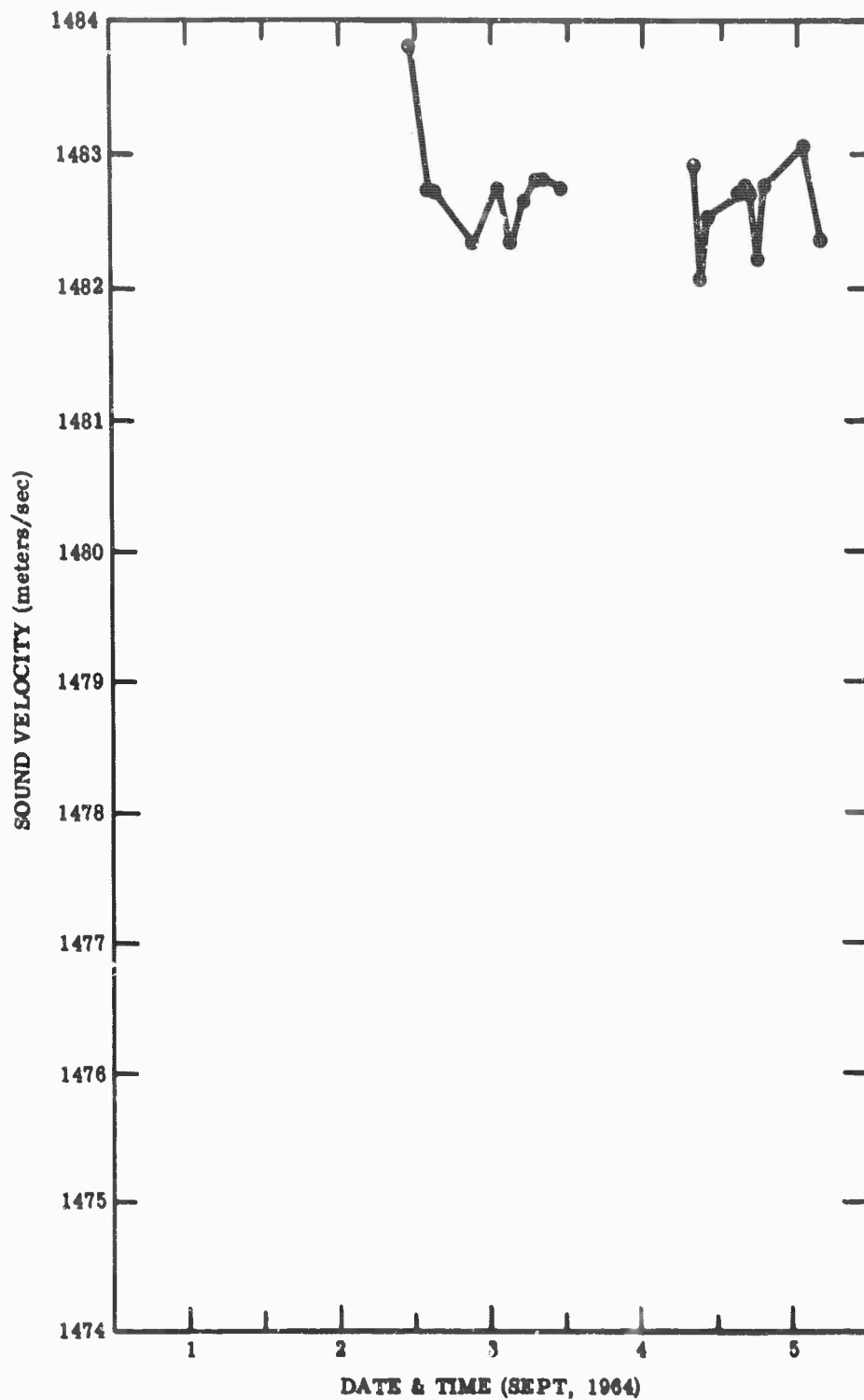


Figure 18 Average Sound Velocity of GM DRL Oahu SOFAR  
Shots Received by Midway MILS Station

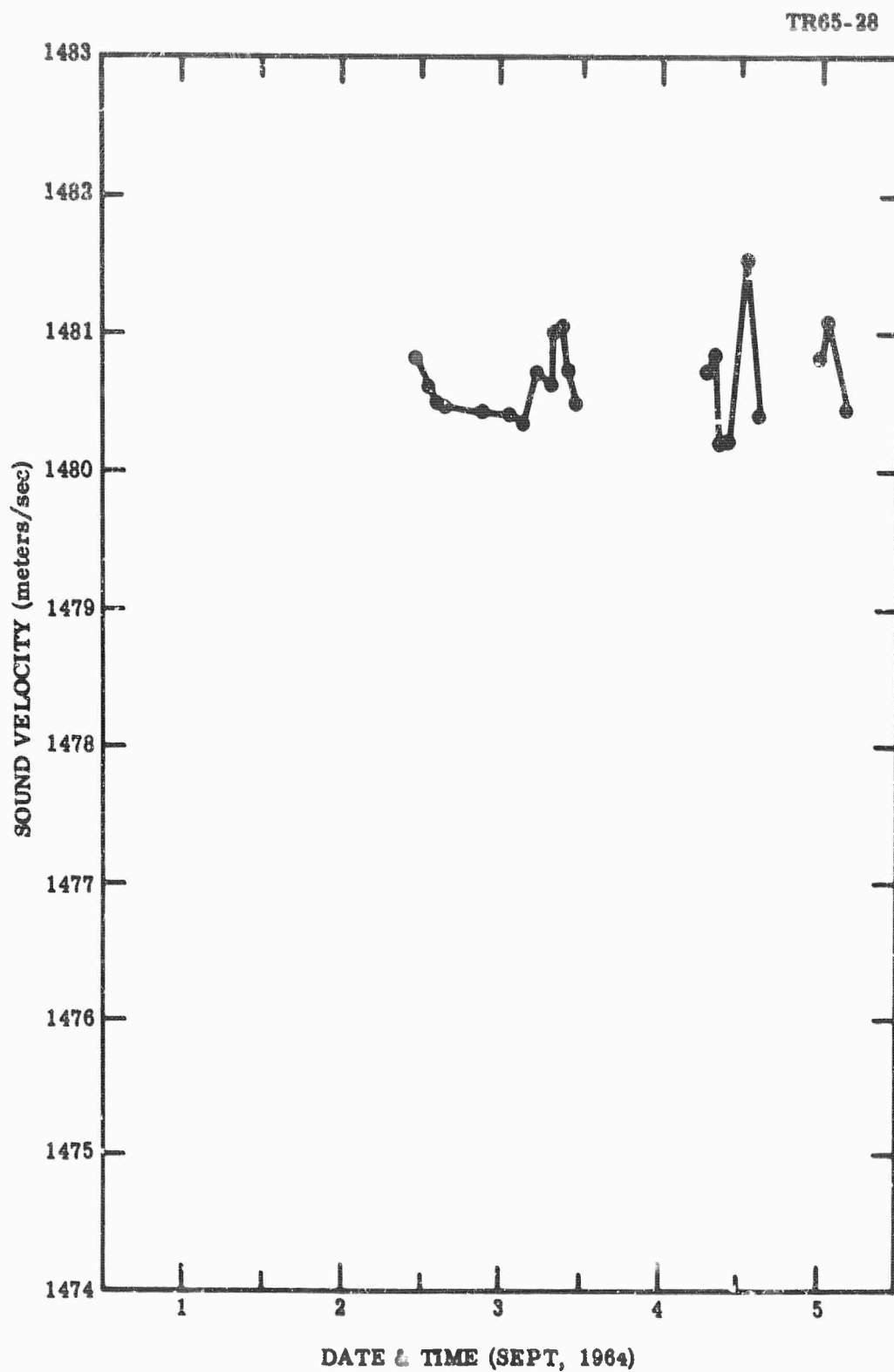


Figure 19 Average Sound Velocity GM DRL Oahu SOFAR  
Shots Received by Eniwetok MILS Station

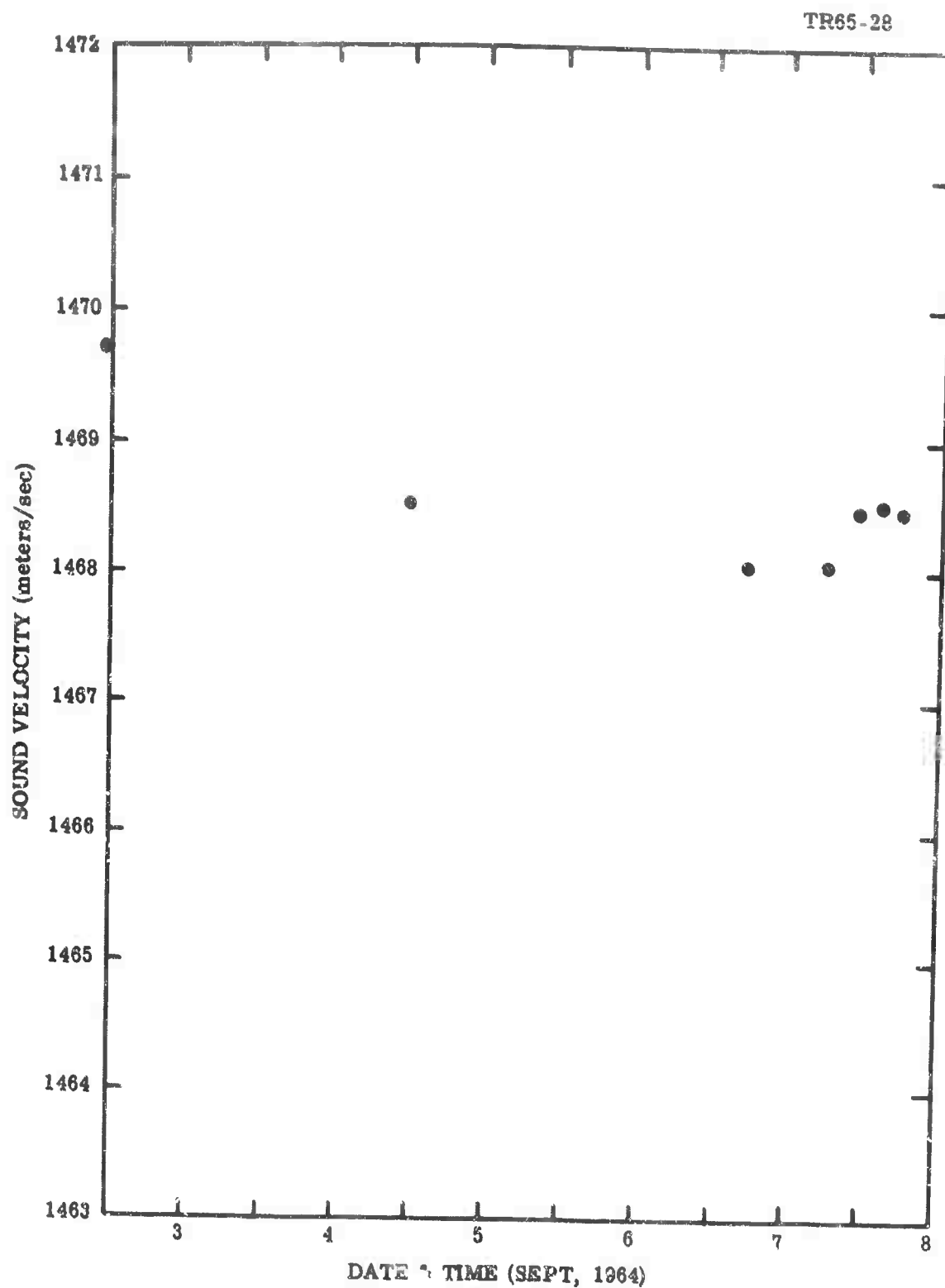


Figure 20 Average Sound Velocity TI Aleutian 2376-lb Shots  
Received by Acoustic Recording Buoy Station

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If the total distance  $D$  is divided into  $N$  increments of equal length,  $D_j$ , in which the SOFAR velocity is approximated by  $C_j$ , Equation (1) reduces to

$$\langle c \rangle = \left[ N \sum_{j=1}^N \frac{1}{C_j} \right]^{-1} \quad (3)$$

The measured velocity from Oahu to the buoy and other west coast receivers is slightly less than the computed; the decrement is about 1 meter per second. Possible reasons for this effect are many. In the first place, Johnson's chart,<sup>(7)</sup> which served as the basis of the computation, was in rather small scale for these purposes; hence, the uncertainty of the computed velocity may be 1/2 meter per second, or so. Another hypothesis assumes that the sound actually traveled farther than the strict geodesic calculation would indicate. Variations in path could be in the horizontal plane, due to horizontal velocity gradients or scattering, or in the vertical plane, due to changes in depth of the SOFAR axis. Such an effect might occur if significant internal wave activity were present. To check the horizontal deviation hypothesis, statistical correlations were run at each West Coast installation between the sound velocity and azimuth of arrival. Results were negative, i.e., there was no significant correlation between deviations from the great circle, as received, and the average sound velocity. The effect of vertical variation in SOFAR axis depth seems to be in the right order of magnitude and could account for reductions in apparent sound velocity of the magnitudes observed. The table below indicates the relationship between wavelength and amplitude to produce a velocity decrement of one meter per second and ten meters per second, assuming a sinusoidal path.

Table I  
PATH AMPLITUDE AND WAVELENGTH PRODUCING  
A GIVEN VELOCITY DECREMENT

|                       | Velocity Decrement<br>1 m/sec | Velocity Decrement<br>10 m/sec |
|-----------------------|-------------------------------|--------------------------------|
| Amplitude<br>(meters) | Wavelength<br>(meters)        | Wavelength<br>(meters)         |
| 10                    | 1200                          | 380                            |
| 25                    | 3000                          | 950                            |
| 50                    | 6000                          | 1900                           |

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Based on the indicated results at the buoy station and others, the net standard deviation at a range of about 2115 nautical miles (3923 km) is about 0.05 km per second. This uncertainty in velocity produces a position uncertainty in the source of about 2.25 kilometers. This statement of uncertainty is one of the main objectives of the experiment. The remainder of the receivers, particularly the MILS station, showed a smaller spread in the data, which would indicate a smaller position uncertainty.

#### 6.4 SOURCE LOCATION

##### General

During the course of the Aleutian experiment several 248-lb bombs were dropped by Navy P2V patrol planes.

Accurate source locations were required for the TI seismic experiment; accordingly ARPA requested GM DRL<sup>(8)</sup> to locate the source of these shots acoustically as a check and as a supplement to the navigational information provided by the aircraft. A similar request was sent to the Hawaii Institute of Geophysics, University of Hawaii. The receiving stations in the GM DRL source location computational net were spaced along the west coast of the United States and throughout the North Central Pacific. Approximately six to eight station times were involved in each location computation. Stations used by the University of Hawaii included those in the North Central Pacific but only one on the west coast of the United States mainland.

##### Source Location Program

Given the arrival time of signals from an acoustic event at three or more known locations on the earth's surface, source time and location are to be determined. Because signal waveforms become distorted during propagation it is difficult to measure arrival times precisely, and errors will appear in the measured data. Furthermore, the average propagation velocity between source and receiver may not be known exactly. Thus, for more than three receiving stations it is quite likely that there is no source location on the earth's surface from

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which the computed and observed arrivals at all stations match precisely. This situation, as is usual when attempting to match an analytic expression to the real world, required curve fitting with a least squares criterion. The source location and time are chosen to minimize the rms deviation of the set measured arrival times from those predicted from the solution.

Because of the non-linearity of the spherical geometry no exact analytical solution is possible for the minimization problem. Good results may be obtained, however, by linearizing the equations through a perturbation approach, i. e., solving for small corrections to approximate solutions. With sufficient iteration any degree of precision may be attained in finding the optimum point consistent with the data. Note that bad input data may cause this point to be an inaccurate solution. The only claim is that the position is the best that the data supports.

In the following analysis a good first guess for source time and location will be assumed. The actual limitations on this first approximation for convergence will be discussed later.

#### Basic Equations

The  $j^{\text{th}}$  station residual is defined as the difference between the observed arrival time  $T_{0j}$ , and the computed arrival time  $T_{cj}$ .

$$s_j = T_{0j} - T_{cj}(L, \lambda, T_0) \quad (4)$$

where

$L$  = longitude

$\lambda$  = latitude

The computed arrival time is a function of the source location and time. For a set of  $n$  stations the ensemble residual is defined as the rms of the individual station residuals.

$$S = \left[ \frac{1}{n} \sum_{j=1}^n s_j^2 \right]^{1/2} \quad (5)$$

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The source location problem is to find the geographical point and origin time that will minimize the ensemble residual. This is effected through maximizing the negative change in  $S$  from the trial point, assuming a planar geometry. The change in  $S$  may be expressed:

$$\Delta S = \frac{-1}{nS} \sum_{j=1}^n s_j \left( \frac{\partial T_{cj}}{\partial L} \Delta L + \frac{T_{cj}}{\partial \lambda} \Delta \lambda + \frac{\partial T_{cj}}{\partial T_0} \Delta T_0 \right) \quad (6)$$

Maximizing the series in parentheses will find an approximate solution to the optimum  $\Delta S$ .

In Figure 21 the initial trial point is  $(L', \lambda', T_0')$  and the new point is  $(L, \lambda, T_0)$ . Plane geometry and long distances to receiving stations are assumed. With this assumption, we set

$$\begin{aligned} \Delta Y &= \Delta L \\ \Delta X &= \cos L \Delta \lambda \end{aligned} \quad (7)$$

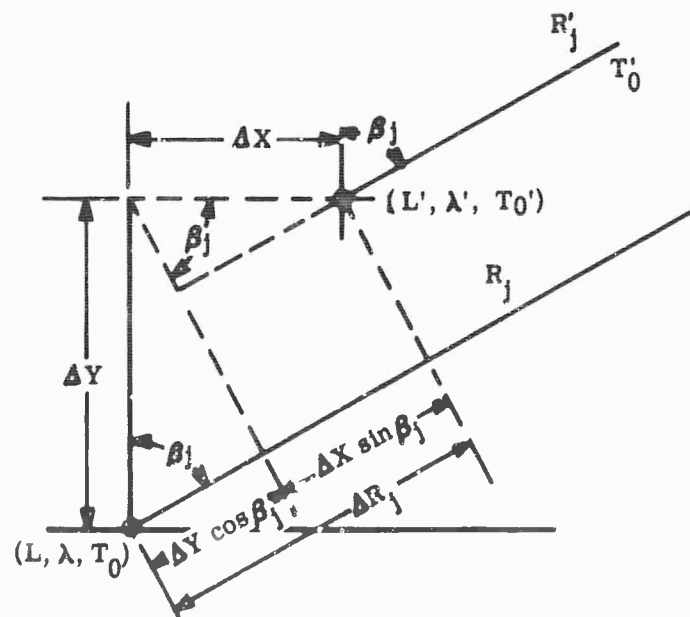


Figure 21 Trial Location Geometry

It can be shown:

$$\frac{\partial T_c}{\partial L} \Delta L = \frac{\Delta Y \cos \beta}{C} \quad (8)$$

$$\frac{\partial T_{c_j}}{\partial \lambda} \Delta \lambda = \frac{\Delta X \sin \beta_j}{r} \quad (9)$$

$$\frac{\partial T_{cj}}{\partial T_0} \Delta T_0 = \Delta T_0 \quad (10)$$

The job is thus to find the  $\Delta X$ ,  $\Delta Y$ , and  $\Delta T_0$  which will minimize  $\sum_j [s_j - \Delta s_j]^2$  with the set of equations

$$\begin{aligned} \Delta X \sin \beta_1 + \Delta Y \cos \beta_1 + C \Delta T_0 &= C \Delta s_1 \\ \dots & \dots \dots \dots \\ \Delta X \sin \beta_j + \Delta Y \cos \beta_j + C \Delta T_0 &= C \Delta s_j \\ \dots & \dots \dots \dots \\ \Delta X \sin \beta_n + \Delta Y \cos \beta_n + C \Delta T_0 &= C \Delta s_n \end{aligned} \quad (11)$$

If there are but three receivers, there are three equations in the set (11), and an exact solution to  $s_j = 0$  is possible, within certain geometric constraints. For four or more receivers a least squares criterion is required. After several iterations  $\Delta X$ ,  $\Delta Y$ , and  $\Delta T_0$  approach zero as  $S$  approaches its minimum. A solution is considered reached when  $\Delta X$  and  $\Delta Y$  are both less than 10 meters.

## Program Mechanics

Appendix III contains a listing of the GM DRL source location program specially configured to solve for the TI 248-lb shot locations using data largely supplied by and in the format of the University of Hawaii epicenter location program. The principal steps in the program are as follows:

- a) Alpha-numeric constants are read in.
- b) Hydrophone station location data (in geodetic radians) and sound velocities in m/sec appropriate to each station are read in and filed by number. Latitudes are converted to geocentric radians. (Average sound velocities to the

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West Coast stations were measured from the TI 2376-lb shots. MILS station velocities were supplied by the University of Hawaii.)

- c) A common starting point for all iteration is read in and converted to radians.
- d) A reading of the time of day is taken from the real-time computer clock.
- e) Arrival times of one shot at each station that received it are read in, and the corresponding station locations are taken from general storage and placed in working arrays. Arrival times are converted to seconds.
- f) The variables  $L$  and  $\lambda$  are given the initial values in radians read in at c) above. The variable  $T_0$  is given a starting value 1689 seconds, earlier than the first arrival time read in.
- g) The great-circle ranges from the trial point to each station are computed using a subroutine GCD. The subroutine also returns the values of the sine and cosine of the true bearing of each station from the trial point.
- h) A sound velocity in radians/sec is computed from the station sound velocity and the average radius of the earth over the path.
- i) The station residuals are formed, Equation (4).
- j) A subroutine LSTSQ3 is called. This solves the system of Equations (11) using the coefficients computed in g) and h) for the values of  $\Delta X$ ,  $\Delta Y$ , and  $\Delta T$  to minimize the sum of the squares of the residuals. The subroutine also returns the resulting value of the rms residual, Equation (5).
- k) The coordinates  $L$ ,  $\lambda$ , and  $T_0$  are corrected with  $\Delta X$ ,  $\cos L$ ,  $\Delta Y$ , and  $\Delta T$ ;  $\lambda$  and  $L$  are reduced modulo  $2\pi$  and to a reasonable latitude respectively.
- l) If the corrections  $\Delta X$  and  $\Delta Y$  are greater than 10 meters the program repeats steps g) - k) until they are both 10 meters or less.
- m) When the solution is finished, the locations are reduced to geodetic degrees, minutes, and seconds, and the time to hours, minutes, and seconds. Residuals are converted to meters. A heading, the final values of all residuals, and the source coordinates are printed out. The source coordinates are also punched out on cards.

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n) A second clock reading is taken and the total elapsed time is computed and printed out.

o) Steps d) - n) are repeated for all shots.

In the production runs for the TI 248-lb shots, the above calculations were run for 6 - 13 hydrophones at 4 - 5 stations to a solution precision of 10 meters in 7 - 12 iterations. The average time was about 2.5 seconds for a complete solution, including all input-output operations. The results are listed in Appendix VI, together with the results of similar runs from the University of Hawaii (using MILS data only) and the radar fixes on the plane at the times of drop.

#### Convergence Behavior

The linear set (11) will always have a solution; however, this solution is not necessarily the solution to the geographical problem. Because the earth is spherical and finite, the assumptions leading to (11) are never exactly true. Thus when the  $\Delta X$ ,  $\Delta Y$ ,  $\Delta T$  are added to the trial parameters, the result is still in geographical error (although usually an order of magnitude better), and the problem must be re-solved to get an even better answer. In the working version the iteration is cut off when  $\Delta X$  and  $\Delta Y$  are both less than 10 meters. The number of iterations necessary to achieve this precision varies according to the accuracy of the first guess. For a first guess within 5 - 10 degrees of the true location, 5 - 7 iterations are adequate to reach the 10-meters precision.

Allowing a first guess of nearly unlimited sloppiness, this technique appears to have a very wide convergence range. The three probable reasons are as follows:

- 1) The test of a successful iteration is whether it moves the trial point closer or farther away from the actual point. Thus, considerable error (in fact,  $\pm 90^\circ$ ) is still tolerable in the direction of movement from the true one.
- 2) The earth's surface is finite and closed. Thus, while some really wild  $\Delta \lambda$  and  $\Delta L$  can arise (e.g.,  $+300^\circ$ ,  $-653^\circ$ ), the trial point is reduced modulo  $360^\circ$  and stays on the surface.
- 3) The third variable, time, is truly linear. Thus, a really bad first guess is more readily corrected.

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The following is an example of the latitude allowable. Received times appropriate to a source time of about 1800 hours and a source location in Hawaii were given to the program. The initial guess was zero hours, zero. Very occasionally, with a really bad first guess, the solution will converge to a local rather than a global minimum. The station residual as a function of position on the earth's surface is very complicated and can have one or more local minima. As an example, the arrival times of TI shot 74 at the MILS and West Coast stations were taken, and for a lattice of points on the earth's surface the best possible source time was calculated and an rms station residual calculated. Iso-residual contours were then interpolated and plotted in (Fig. 22) for a 100-deg square in the Pacific Ocean.

As may be seen, besides the absolute minimum of the real solution, there is one other local minimum near  $9^{\circ}\text{N}$ ,  $158^{\circ}\text{W}$ . Viewed in this manner, the program solution becomes one of rolling to the lowest point on the map. The weak minimum did capture several test solutions. There is little danger of mistaking this solution for the true one, however, since the residual has a value of 750 km at this point. In a production version of the program some algorithm should be used to leap out of such false minima. One successful algorithm was to drop one hydrophone from the solution and resolve. This yielded the correct answer in every case tried but was expensive in terms of computer time. Perhaps merely solving the problem over from a different starting point would be best.

The contours in Figure 22 are a very special case corresponding to one particular receiver configuration and one particular actual source location. The contours could change greatly by changing the numbers or locations of hydrophones or by changing the general source location. A study consisting of systematic variations of these parameters might prove valuable for optimizing patterns of receiving stations.

#### Results of Computations

Source locations for the 248-lb Aleutian shots by three agents and two methods (GM DRL acoustical, University of Hawaii acoustical, and the aircraft navigational) are presented in Appendix VI. A measure of the goodness of fit of a source

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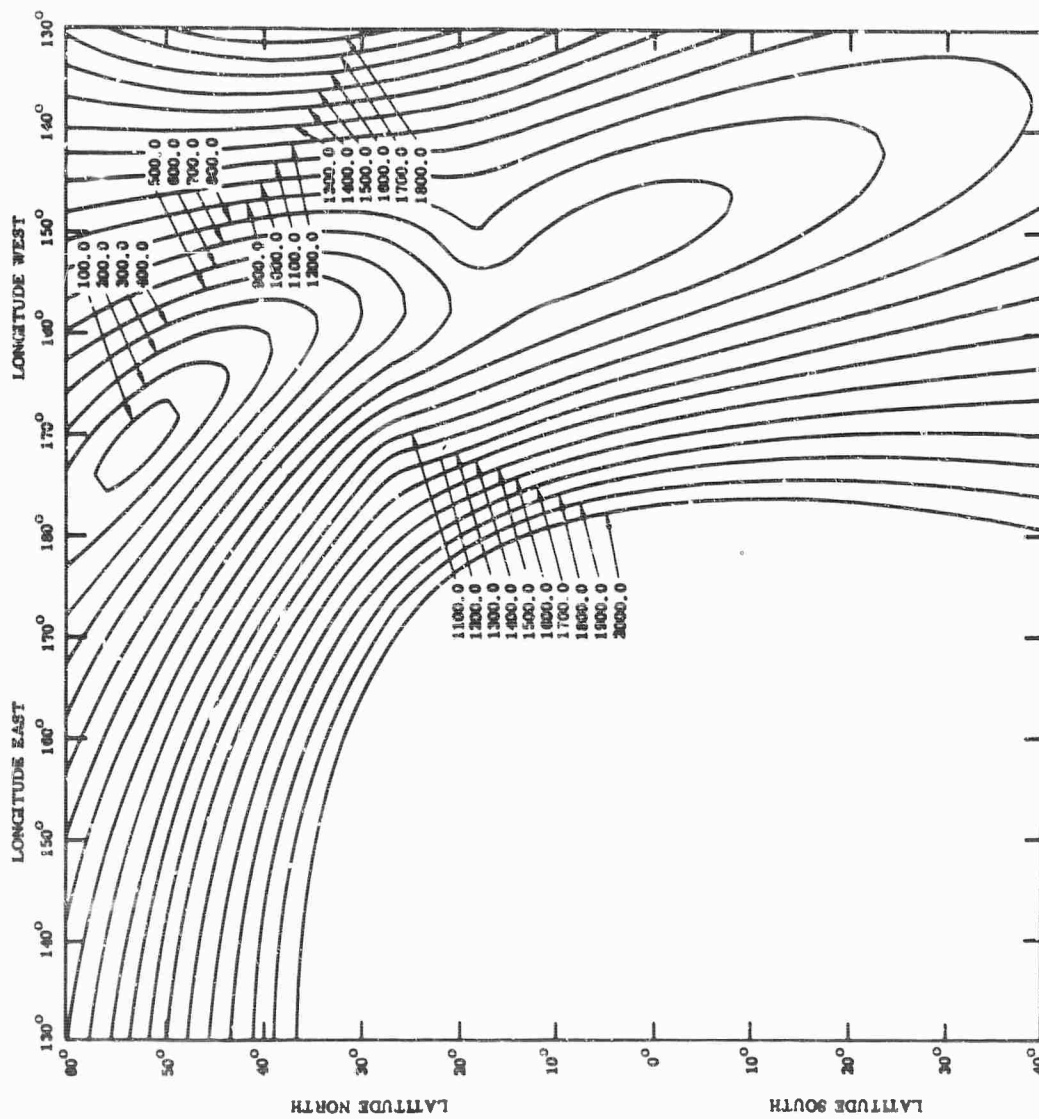


Figure 22 Pacific Ocean Area for Illustrative Source Location Problem

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location calculation to the data is the ensemble residual. For the GM DRL computation, the ensemble residual is the rms result of the individual station residuals expressed in meters. The station residual is the distance the station would have to be moved toward or away from the assumed source location to match the computed and actual arrival time. University of Hawaii residuals are in seconds of time. The two are convertible to one another through the nominal sound velocity, 1480 meters per second. Another indicator in a positional calculation where more than one method is used is the geographical distance between locations, determined by separate means. The averages of this "distance contradiction" among the three location computation agents, together with mean ensemble residuals for the entire group of 248-lb shots, are indicated below.

**Average Ensemble Residuals**

|        |             |              |
|--------|-------------|--------------|
| GM DRL | 4026 meters | 2.72 seconds |
| U of H | 3049 meters | 2.06 seconds |

**Average Location Contradictions**

|        |            |                 |
|--------|------------|-----------------|
| GM DRL | Navigation | 11.9 kilometers |
| U of H | Navigation | 12.0 kilometers |
| GM DRL | U of H     | 7.79 kilometers |

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Table II  
AVERAGE SOUND VELOCITY  
COMPUTED AND OBSERVED

| Source | Receiver | $\bar{V}_p$ (m/sec) | $\bar{V}_e$ (m/sec) | $\bar{V}_e - \bar{V}_p$ | S    | N  |
|--------|----------|---------------------|---------------------|-------------------------|------|----|
| 1      | 3        | 1480.66             | 1482.09             | 1.43                    | 0.31 | 22 |
| 1      | 9        | --                  | 1483.32             | --                      | --   | -- |
| 1      | 10       | 1482.69             | 1484.11             | 1.42                    | 0.35 | 20 |
| 1      | 11       | 1479.27             | 1480.87             | 1.60                    | 0.85 | 50 |
| 2      | 11       | 1468.55             | 1472.87             | 4.32                    | 0.51 | 7  |

Legend:  $\bar{V}_p$  - determined from observed data and GM DRL program

$\bar{V}_e$  - estimated from U of H contour plots

S - standard deviation for  $\bar{V}_p$

N - number of points used to determine  $\bar{V}_p$

Receiver: 8 - Midway

9 - Wake Island

10 - Eniwetok

11 - GM DRL acoustic monitoring buoy

Source: 1 - GM DRL Oahu shots

2 - TI Aleutian Shots

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# APPENDIX I

## SOURCE DATA SUMMARY

This appendix includes the listings of the final source logs for the TI 2376-lb Aleutian shots as reported in Reference 9, and the GM DRL Oahu shots used in all calculations of sound velocity. These numbers were assembled from various logs kept at the time of the shots. The reduction is briefly described in Section 6. The column headings are self-explanatory.

### SOURCE TIMES AND LOCATIONS TI 2376 LB SHOTS

| SHOT | DATE     | GCT        | LATITUDE  | LONGITUDE  | DEPTH  | CHARGE | WATER |
|------|----------|------------|-----------|------------|--------|--------|-------|
|      | MO DY YR | HRMN SEC   | DG MN SC  | DEG MN SC  | METERS | WT LBS | DEPTH |
| 2 23 | 9/ 2/64  | 2311 00.00 | 51 29 10N | 175 52 30W | 91.    | 2376.  | 3380  |
| 2 22 | 9/ 4/64  | 2336 59.75 | 51 22 15N | 176 42 22W | 91.    | 2376.  | 2104  |
| 2 21 | 9/ 5/64  | 0246 00.06 | 51 20 10N | 177 20 55W | 91.    | 2376.  | 2122  |
| 2 20 | 9/ 5/64  | 0354 00.02 | 51 17 43N | 177 49 55W | 91.    | 2376.  | 1220  |
| 2 11 | 9/ 7/64  | 0527 00.00 | 51 03 30N | 175 51 30W | 91.    | 2376.  | 3475  |
| 2 13 | 9/ 7/64  | 1824 00.02 | 51 14 45N | 174 19 00W | 91.    | 2376.  | 4505  |
| 2 26 | 9/ 7/64  | 2305 00.35 | 51 45 50N | 173 35 30W | 91.    | 2376.  | 2415  |
| 2 25 | 9/ 8/64  | 0230 59.75 | 51 41 30N | 174 14 30W | 91.    | 2376.  | 3038  |
| 2 24 | 9/ 8/64  | 0557 00.17 | 51 35 55N | 175 00 45W | 91.    | 2376.  | 3075  |
| 2 19 | 9/ 8/64  | 2341 00.05 | 51 11 05N | 178 27 20W | 91.    | 2376.  | 2453  |
| 2 18 | 9/ 9/64  | 0627 00.25 | 51 02 30N | 178 55 50W | 91.    | 2376.  | 3075  |
| 2 32 | 9/10/64  | 0522 00.14 | 51 46 42N | 178 33 45W | 91.    | 2376.  | 1510  |
| 2 62 | 9/11/64  | 0931 59.92 | 52 12 00N | 178 05 40W | 61.    | 2376.  | 3185  |
| 2 45 | 9/12/64  | 0155 59.89 | 52 08 00N | 179 01 20W | 61.    | 2376.  | 2765  |
| 2 42 | 9/12/64  | 0345 00.00 | 51 51 15N | 179 33 08W | 61.    | 2376.  | 1757  |
| 2 40 | 9/12/64  | 2030 59.92 | 51 51 50N | 178 34 56E | 61.    | 2376.  | 586   |
| 2 41 | 9/13/64  | 0201 00.15 | 51 40 15N | 179 28 15W | 61.    | 2376.  | 1244  |
| 2 30 | 9/13/64  | 0605 59.97 | 51 21 55N | 179 47 35W | 61.    | 2376.  | 1538  |
| 2 46 | 9/15/64  | 1906 00.20 | 52 20 22N | 177 16 25W | 91.    | 2376.  | 3335  |
| 2 47 | 9/17/64  | 2206 00.13 | 52 21 30N | 176 42 55W | 91.    | 2376.  | 3475  |
| 2 59 | 9/18/64  | 0122 00.21 | 52 45 13N | 176 43 30W | 91.    | 2376.  | 3550  |
| 2 54 | 9/18/64  | 1904 00.02 | 51 28 20N | 179 23 10W | 91.    | 2376.  | 1061  |
| 2 17 | 9/18/64  | 2256 00.23 | 51 02 12N | 179 44 50W | 91.    | 2376.  | 5755  |

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## SOURCE TIMES AND LOCATIONS GM/DRL SHOTS

| SHOT | DATE |     |      | GCT  |       | LATITUDE |     |     | LONGITUDE |     |     | DEPTH<br>METERS | CHARGE<br>WT LBS | EXPLOSION<br>STRENGTH |
|------|------|-----|------|------|-------|----------|-----|-----|-----------|-----|-----|-----------------|------------------|-----------------------|
|      | MO   | DAY | YR   | HR   | MIN   | DEG      | MIN | SEC | DEG       | MIN | SEC |                 |                  |                       |
| 1    | 1    | 9/  | 1/64 | 0801 | 08.00 | 21       | 48  | 25N | 158       | 10  | 17W | 720.            | 4.50             | GOOD                  |
| 1    | 2    | 9/  | 1/64 | 1000 | 32.90 | 21       | 48  | 00N | 158       | 10  | 30W | 720.            | 4.50             | GOOD                  |
| 1    | 5    | 9/  | 1/64 | 1600 | 58.60 | 21       | 47  | 55N | 158       | 13  | 28W | 649.            | 4.50             | GOOD                  |
| 1    | 6    | 9/  | 1/64 | 1800 | 47.40 | 21       | 47  | 19N | 158       | 11  | 9W  | 732.            | 4.50             | GOOD                  |
| 1    | 7    | 9/  | 1/64 | 2003 | 26.00 | 21       | 47  | 39N | 158       | 10  | 43W | 707.            | 4.50             | GOOD                  |
| 1    | 8    | 9/  | 1/64 | 2201 | 00.70 | 21       | 47  | 27N | 158       | 10  | 52W | 676.            | 4.50             | GOOD                  |
| 1    | 9    | 9/  | 2/64 | 0002 | 54.80 | 21       | 47  | 26N | 158       | 11  | 4W  | 947.            | 4.50             | GOOD                  |
| 1    | 10   | 9/  | 2/64 | 0500 | 00.07 | 21       | 48  | 2N  | 158       | 10  | 42W | 711.            | 4.50             | GOOD                  |
| 1    | 11   | 9/  | 2/64 | 0800 | 32.00 | 21       | 48  | 8N  | 158       | 10  | 55W | 879.            | 4.50             | DUD                   |
| 1    | 12   | 9/  | 2/64 | 1100 | 53.70 | 21       | 47  | 56N | 158       | 11  | 7W  | 872.            | 4.50             | GOOD                  |
| 1    | 13   | 9/  | 2/64 | 1303 | 29.20 | 21       | 48  | 4N  | 158       | 11  | 3W  | 801.            | 4.50             | GOOD                  |
| 1    | 15   | 9/  | 2/64 | 1700 | 35.00 | 21       | 48  | 11N | 158       | 10  | 41W | 771.            | 4.50             | GOOD                  |
| 1    | 16   | 9/  | 2/64 | 1900 | 30.00 | 21       | 48  | 2N  | 158       | 10  | 46W | 744.            | 4.50             | CAPS                  |
| 1    | 17   | 9/  | 2/64 | 2100 | 27.70 | 21       | 47  | 40N | 158       | 11  | 7W  | 676.            | 4.50             | CAPS                  |
| 1    | 18   | 9/  | 2/64 | 2302 | 54.78 | 21       | 48  | 5N  | 158       | 10  | 42W | 750.            | 4.50             | GOOD                  |
| 1    | 19   | 9/  | 3/64 | 0102 | 07.50 | 21       | 48  | 5N  | 158       | 10  | 42W | 803.            | 9.00             | GOOD                  |
| 1    | 20   | 9/  | 3/64 | 0200 | 46.00 | 21       | 48  | 6N  | 158       | 10  | 48W | 843.            | 4.50             | GOOD                  |
| 1    | 21   | 9/  | 3/64 | 0300 | 50.00 | 21       | 48  | 8N  | 158       | 10  | 49W | 850.            | 9.00             | GOOD                  |
| 1    | 22   | 9/  | 3/64 | 0904 | 11.40 | 21       | 47  | 57N | 158       | 11  | 4W  | 881.            | 9.00             | GOOD                  |
| 1    | 23   | 9/  | 3/64 | 1100 | 44.70 | 21       | 47  | 48N | 158       | 11  | 25W | 854.            | 4.50             | CAPS                  |
| 1    | 24   | 9/  | 3/64 | 1304 | 42.70 | 21       | 47  | 58N | 158       | 11  | 10W | 863.            | 4.50             | GOOD                  |
| 1    | 25   | 9/  | 3/64 | 1500 | 40.70 | 21       | 47  | 35N | 158       | 11  | 25W | 854.            | 4.50             | GOOD                  |
| 1    | 26   | 9/  | 3/64 | 1700 | 29.39 | 21       | 48  | 2N  | 158       | 10  | 44W | 845.            | 4.50             | GOOD                  |
| 1    | 27   | 9/  | 3/64 | 1800 | 30.40 | 21       | 47  | 0N  | 158       | 10  | 41W | 858.            | 4.50             | GOOD                  |
| 1    | 28   | 9/  | 3/64 | 1900 | 47.20 | 21       | 48  | 7N  | 158       | 10  | 35W | 820.            | 7.75             | GOOD                  |
| 1    | 29   | 9/  | 3/64 | 2000 | 46.29 | 21       | 48  | 7N  | 158       | 10  | 37W | 761.            | 4.50             | GOOD                  |
| 1    | 30   | 9/  | 3/64 | 2101 | 10.00 | 21       | 47  | 0N  | 158       | 10  | 54W | 730.            | 13.50            | GOOD                  |
| 1    | 31   | 9/  | 3/64 | 2200 | 38.60 | 21       | 47  | 59N | 158       | 10  | 50W | 860.            | 4.50             | GOOD                  |
| 1    | 32   | 9/  | 3/64 | 2300 | 38.40 | 21       | 48  | 3N  | 158       | 10  | 45W | 860.            | 11.25            | GOOD                  |
| 1    | 33   | 9/  | 4/64 | 0000 | 26.60 | 21       | 47  | 0N  | 158       | 10  | 46W | 802.            | 4.50             | GOOD                  |
| 1    | 34   | 9/  | 4/64 | 0100 | 25.40 | 21       | 48  | 1N  | 158       | 10  | 57W | 774.            | 11.25            | GOOD                  |
| 1    | 35   | 9/  | 4/64 | 0200 | 22.45 | 21       | 48  | 7N  | 158       | 10  | 43W | 802.            | 4.50             | GOOD                  |
| 1    | 36   | 9/  | 4/64 | 0304 | 20.50 | 21       | 48  | 15N | 158       | 10  | 39W | 788.            | 9.00             | GOOD                  |
| 1    | 37   | 9/  | 4/64 | 0400 | 41.20 | 21       | 48  | 16N | 158       | 10  | 59W | 766.            | 13.50            | GOOD                  |
| 1    | 38   | 9/  | 4/64 | 0500 | 29.80 | 21       | 48  | 2N  | 158       | 10  | 53W | 817.            | 4.50             | GOOD                  |
| 1    | 39   | 9/  | 4/64 | 0604 | 53.40 | 21       | 47  | 22N | 158       | 13  | 6W  | 831.            | 9.00             | GOOD                  |
| 1    | 40   | 9/  | 4/64 | 0702 | 03.20 | 21       | 47  | 53N | 158       | 10  | 56W | 729.            | 4.50             | GOOD                  |
| 1    | 41   | 9/  | 4/64 | 0801 | 01.20 | 21       | 48  | 1N  | 158       | 10  | 24W | 883.            | 9.00             | GOOD                  |
| 1    | 42   | 9/  | 4/64 | 0900 | 00.60 | 21       | 48  | 10N | 158       | 10  | 34W | 841.            | 4.50             | GOOD                  |
| 1    | 43   | 9/  | 4/64 | 1000 | 34.80 | 21       | 48  | 4N  | 158       | 10  | 42W | 773.            | 13.50            | GOOD                  |
| 1    | 44   | 9/  | 4/64 | 1701 | 14.40 | 21       | 47  | 44N | 158       | 10  | 46W | 801.            | 9.00             | GOOD                  |
| 1    | 45   | 9/  | 4/64 | 1801 | 49.60 | 21       | 48  | 8N  | 158       | 9   | 50W | 831.            | 4.50             | GOOD                  |
| 1    | 46   | 9/  | 4/64 | 1900 | 38.60 | 21       | 48  | 4N  | 158       | 10  | 26W | 704.            | 4.50             | GOOD                  |
| 1    | 47   | 9/  | 4/64 | 2000 | 37.40 | 21       | 48  | 10N | 158       | 10  | 16W | 589.            | 4.50             | GOOD                  |
| 1    | 48   | 9/  | 4/64 | 2101 | 36.00 | 21       | 47  | 37N | 158       | 10  | 29W | 586.            | 9.00             | GOOD                  |
| 1    | 49   | 9/  | 4/64 | 2200 | 19.80 | 21       | 48  | 6N  | 158       | 9   | 56W | 831.            | 13.50            | GOOD                  |
| 1    | 50   | 9/  | 5/64 | 0103 | 57.20 | 21       | 47  | 57N | 158       | 10  | 19W | 766.            | 9.00             | GOOD                  |
| 1    | 51   | 9/  | 5/64 | 0300 | 49.30 | 21       | 47  | 28N | 158       | 10  | 29W | 784.            | 9.00             | GOOD                  |
| 1    | 52   | 9/  | 5/64 | 0400 | 43.10 | 21       | 47  | 38N | 158       | 10  | 13W | 659.            | 9.00             | GOOD                  |
| 1    | 53   | 9/  | 5/64 | 0502 | 46.80 | 21       | 47  | 49N | 158       | 10  | 0W  | 624.            | 9.00             | GOOD                  |
| 1    | 54   | 9/  | 5/64 | 0600 | 25.60 | 21       | 47  | 49N | 158       | 10  | 26W | 663.            | 22.00            | GOOD                  |
| 1    | 55   | 9/  | 5/64 | 0700 | 23.65 | 21       | 47  | 31N | 158       | 10  | 5W  | 591.            | 18.00            | GOOD                  |
| 1    | 56   | 9/  | 5/64 | 1200 | 32.00 | 21       | 47  | 43N | 158       | 10  | 43W | 667.            | 9.00             | GOOD                  |
| 1    | 57   | 9/  | 5/64 | 1300 | 31.20 | 21       | 47  | 55N | 158       | 11  | 36W | 684.            | 18.00            | GOOD                  |
| 1    | 58   | 9/  | 5/64 | 1402 | 12.0  | 21       | 37  | 52N | 158       | 8   | 57W | 671.            | 18.00            | DUD                   |
| 1    | 60   | 9/  | 5/64 | 1600 | 48.70 | 21       | 47  | 50N | 158       | 10  | 59W | 615.            | 18.00            | GOOD                  |

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# APPENDIX IIa GM BUOY LOG

## GM OAHU SHOTS

The following is a log taken from the GM DRL buoy roll chart. The column headings for station, date, and shot number are self-explanatory, as are those for hours and minutes. The fraction of a minute and amplitudes are all measured in hundredths of an inch. The last number is a calibration, the number of hundredths of inches per minute. Thus, the first return arrived at 0845 and  $\left(\frac{.68}{2.37}\right) \times 60$  seconds, lasted for  $\left(\frac{.32}{2.37}\right) \times 60$  seconds, and had an amplitude of 1.75 inches.

## ALEUTIAN TI SHOTS

A reproduction of the receiver log is shown. In contradistinction to the Oahu shot log, the column labeled TIME indicates the nearest time fiduciary mark preceding the onset of the arrival signal. This time is given in hours, minutes and millimeters. The column labeled DUR gives the duration time of the arrival signal in millimeters and SOFARR gives the time elapsed in hundredths of millimeters from the fiduciary mark to the arrival of the axial ray. The conversion factor is 60.5 millimeters per 60 seconds. Thus, for shot 23 the axial ray arrives at 2405 hours plus  $(60/60.5) (03 + 30.00)$  seconds, and the duration is  $(60/60.5) (73)$  seconds.

## ARRIVAL TIMES OF TI ALEUTIAN SHOTS AT GM/DRL BUOY

| Stn<br>No | Date<br>mo dy yr | Shot<br>no | Time<br>hr mn mm | Dur<br>mm | SOFARR<br>mm |
|-----------|------------------|------------|------------------|-----------|--------------|
| 11        | 090264           | 23         | 240503           | 73        | 3000         |
| 11        | 090464           | 22         | 243154           | 76        | 7150         |
| 11        | 090764           | 11         | 062113           | 76        | 3200         |
| 11        | 090764           | 13         | 191700           | 74        | 1900         |
| 11        | 090764           | 26         | 235730           | 64        | 4650         |
| 11        | 090764           | 25         | 032400           | 64        | 1600         |
| 11        | 090864           | 24         | 065034           | 72        | 5250         |

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## ARRIVAL TIMES GM/DRL OAHU SHOTS AT GM/DRL BUOY

| STN<br>NO       | DATE SHOT<br>MOYYRNO | TIME<br>HRMN IN | AMPDUR<br>IN IN | IN/<br>IN MIN |
|-----------------|----------------------|-----------------|-----------------|---------------|
| 110070901640101 |                      | 0845068         | 175032          | 237           |
| 110070901640201 |                      | 1044185         | 145025          | 238           |
| 110070901640501 |                      | 1645054         | 123029          | 238           |
| 110070901640601 |                      | 1844238         | 175030          | 239           |
| 110070901640701 |                      | 2047154         | 158031          | 237           |
| 110070901640801 |                      | 2245054         | 177033          | 238           |
| 110070902640901 |                      | 0747034         | 185034          | 239           |
| 110070902641001 |                      | 0544056         | 179026          | 238           |
| 110070902641201 |                      | 1145029         | 178028          | 238           |
| 110070902641301 |                      | 1347165         | 165031          | 238           |
| 110070902641501 |                      | 1744193         | 135025          | 238           |
| 110070902641801 |                      | 2347034         | 172030          | 237           |
| 110070903641901 |                      | 0146045         | 173036          | 238           |
| 110070903642001 |                      | 0244237         | 172027          | 238           |
| 110070903642101 |                      | 0344253         | 174034          | 238           |
| 110070903642201 |                      | 0948098         | 110023          | 238           |
| 110070903642401 |                      | 1348229         | 178027          | 238           |
| 110070903642501 |                      | 1544218         | 178033          | 238           |
| 110070903642601 |                      | 1744430         | 155026          | 605           |
| 110070903642701 |                      | 1844179         | 172030          | 238           |
| 110070903642801 |                      | 1944243         | 175038          | 238           |
| 110070903642901 |                      | 2044258         | 179032          | 238           |
| 110070903643001 |                      | 2145095         | 183034          | 238           |
| 110070903643101 |                      | 2244532         | 168026          | 605           |
| 110070903643201 |                      | 2344210         | 190040          | 238           |
| 110070904643301 |                      | 0044162         | 178035          | 238           |
| 110070904643401 |                      | 0144160         | 182036          | 238           |
| 110070904643501 |                      | 0244148         | 166030          | 238           |
| 110070904643601 |                      | 0348141         | 172033          | 238           |
| 110070904643701 |                      | 0444234         | 174034          | 239           |
| 110070904643801 |                      | 0544183         | 150025          | 239           |
| 110070904643901 |                      | 0649040         | 180032          | 239           |
| 110070904644001 |                      | 0746071         | 165029          | 238           |
| 110070904644101 |                      | 0845061         | 180029          | 238           |
| 110070904644201 |                      | 0944060         | 165028          | 238           |
| 110070904644301 |                      | 1044194         | 175030          | 238           |
| 110070904644401 |                      | 1745110         | 062015          | 236           |
| 110070904644501 |                      | 1845250         | 135028          | 238           |
| 110070904644601 |                      | 1944208         | 176030          | 238           |
| 110070904644701 |                      | 2044205         | 158030          | 239           |
| 110070904644801 |                      | 2145198         | 156030          | 239           |
| 110070904644901 |                      | 2244134         | 175034          | 239           |
| 110070905645001 |                      | 0148050         | 184034          | 239           |
| 110070905645101 |                      | 0344255         | 173023          | 239           |
| 110070905645201 |                      | 0444230         | 183026          | 239           |
| 110070905645301 |                      | 0546244         | 192032          | 239           |
| 110070905645401 |                      | 0644157         | 132021          | 239           |
| 110070905645501 |                      | 0744150         | 100025          | 239           |
| 110070905645601 |                      | 1244186         | 098025          | 239           |
| 110070905645701 |                      | 1344205         | 060019          | 239           |
| 110070905646001 |                      | 1644254         | 178034          | 239           |

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## APPENDIX IIb

### MILS STATION RECEIVED DATA LOG

The following listing shows the recorded date at MILS stations Eniwetok and Midway of the GM DRL Oahu shots.

The column headings are self-explanatory.

#### ARRIVAL TIMES GM/DRL OAHU SHOTS AT MIDWAY

| STN<br>NO | DATE<br>MOYYR | SHOT<br>NO | TIME<br>HRMN | DUR<br>SEC | S<br>CH1 | FAR<br>CH2 | ARRIVAL<br>CH3 | SEC<br>CH4 | SHOT<br>BRG | RIS<br>DB | BG<br>DBV | A<br>A | GOAO |
|-----------|---------------|------------|--------------|------------|----------|------------|----------------|------------|-------------|-----------|-----------|--------|------|
|           | 9             | 264        | 18           | 12325      |          | 1274       | 377            |            |             |           |           |        |      |
|           | 9             | 364        | 19           | 10124      |          | 1403       | 506            |            |             |           |           |        |      |
|           | 9             | 364        | 20           | 10223      |          | 1188       | 290            |            |             |           |           |        |      |
|           | 9             | 364        | 21           | 10323      |          | 1228       | 331            |            |             |           |           |        |      |
|           | 9             | 364        | 22           | 10926      |          | 1441       | 543            |            |             |           |           |        |      |
|           | 9             | 364        | 24           | 11327      |          | 1153       | 255            |            |             |           |           |        |      |
|           | 9             | 364        | 25           | 11523      |          | 1133       | 237            |            |             |           |           |        |      |
|           | 9             | 364        | 26           | 11723      |          | 1021       | 124            |            |             |           |           |        |      |
|           | 9             | 364        | 28           | 11923      |          | 1201       | 304            |            |             |           |           |        |      |
|           | 9             | 364        | 29           | 12023      |          | 1188       | 291            |            |             |           |           |        |      |
|           | 9             | 364        | 30           | 12123      |          | 1428       | 530            |            |             |           |           |        |      |
|           | 9             | 364        | 31           | 12223      |          | 1112       | 216            |            |             |           |           |        |      |
|           | 9             | 364        | 32           | 12323      |          | 1113       | 216            |            |             |           |           |        |      |
|           | 9             | 464        | 46           | 11923      |          | 1116       | 217            |            |             |           |           |        |      |
|           | 9             | 464        | 47           | 12023      |          | 1104       | 207            |            |             |           |           |        |      |
|           | 9             | 464        | 48           | 12124      |          | 1097       | 197            |            |             |           |           |        |      |
|           | 9             | 464        | 49           | 12223      |          | 938        | 041            |            |             |           |           |        |      |
|           | 9             | 564        | 50           | 10126      |          | 1296       | 398            |            |             |           |           |        |      |
|           | 9             | 564        | 51           | 10323      |          | 1229       | 331            |            |             |           |           |        |      |
|           | 9             | 564        | 56           | 11223      |          | 1048       | 151            |            |             |           |           |        |      |
|           | 9             | 564        | 57           | 11323      |          | 1027       | 128            |            |             |           |           |        |      |
|           | 9             | 564        | 60           | 11623      |          | 1215       | 318            |            |             |           |           |        |      |
|           | 9             | 264        | 18           | 12351      |          | 420        | 476            | 342        | 044         |           |           |        |      |
|           | 9             | 364        | 20           | 10248      |          | 952        | 1007           | 873        | 555         |           |           |        |      |
|           | 9             | 364        | 21           | 10348      |          | 992        | 1050           | 913        | 596         |           |           |        |      |
|           | 9             | 364        | 22           | 10952      |          | 610        | 669            | 536        | 215         |           |           |        |      |
|           | 9             | 364        | 24           | 11352      |          | 914        | 971            | 838        | 517         |           |           |        |      |
|           | 9             | 364        | 25           | 11548      |          | 899        | 957            | 820        | 503         |           |           |        |      |
|           | 9             | 364        | 26           | 11748      |          | 788        | 844            | 706        | 391         |           |           |        |      |
|           | 9             | 364        | 28           | 11948      |          | 965        | 1023           | 888        | 572         |           |           |        |      |
|           | 9             | 364        | 29           | 12048      |          | 955        | 1012           | 879        | 556         |           |           |        |      |
|           | 9             | 364        | 32           | 12348      |          | 876        | 935            | 798        | 481         |           |           |        |      |
|           | 9             | 464        | 47           | 12048      |          | 869        | 924            | 792        | 475         |           |           |        |      |
|           | 9             | 464        | 48           | 12149      |          | 868        | 926            | 783        | 475         |           |           |        |      |
|           | 9             | 464        | 49           | 12248      |          | 704        | 758            | 624        | 304         |           |           |        |      |
|           | 9             | 564        | 51           | 10348      |          | 988        | 1046           | 910        | 591         |           |           |        |      |
|           | 9             | 564        | 52           | 10448      |          | 928        | 984            | 849        | 532         |           |           |        |      |
|           | 9             | 564        | 53           | 10550      |          | 969        | 1026           | 892        | 571         |           |           |        |      |
|           | 9             | 564        | 54           | 10649      |          | 162        | 218            | 086        |             |           |           |        |      |
|           | 9             | 564        | 55           | 10748      |          | 735        | 791            | 659        | 339         |           |           |        |      |
|           | 9             | 564        | 57           | 11348      |          | 788        | 846            | 710        | 393         |           |           |        |      |
|           | 9             | 564        | 60           | 11648      |          | 984        | 1040           | 907        | 587         |           |           |        |      |

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## APPENDIX III

### SOFAR VELOCITY PROGRAM

The following is a listing of the program used to convert source and receiver logs into average sound velocities. The program mechanics are briefly described in Section 6. The coding is done in IBM 7040 Fortran IV, and the program was run on an IBM 7040 computer.

```

C PROGRAM TO COMPUTE AVERAGE SOUND VELOCITY FROM SOURCE AND STATION LOGS
C VW MCLENNAN 1/16/65
  DIMENSION IMO(100),SDAY(100),SHR(100),SMN(100),SSEC(100),SLAT(100)
  1,SLNG(100),SDEPTH(100),SWT(100),SPER(100),RSC(4),N1(10),N2(60)
  2 ,RCLAT(4),RCLNG(4),RDEPTH(4),LABEL(56)
  REAL N
  READ 2,N1,N2
  2 FORMAT(10A1,35A2/25A2)
  READ 3,N,S,F,W,GOOD
  3 FORMAT (4A1,A4)
  READ 27,LABEL
  22 FORMAT(17A6,A2)
  4 READ 5,ISRC,ISHOT,IMO(ISHOT),SDAY(ISHOT),SHR(ISHOT),SMN(ISHOT),
  1SSEC(ISHOT),SLATDG,SLATMN,SLATSC,SLATNS,SLNGDG,SLNGMN,SLNGSC,
  2 SLNGEW,SDEPTH(ISHOT),SWT(ISHOT),SPER(ISHOT)
  5 FORMAT( 12,2I3,1X,F2.0,4X,2F2.0,F6.2,1X,3F3.0,A1,2X,3F3.0,A1,3X,
  1 F4.0,F7.2,1X,A4)
  IF(ISHOT.EQ.100)GO TO 10
  SLATRD=.174532925E-1*(SLATDG +SLATMN/60. +SLATSC/3600.)
  SLAT(ISHOT)=SLATRD-.33726712E-2*SIN(2.*SLATRD)+.5687E-5*SIN(4.*
  1 SLATRD)
  IF(SLATNS.EQ.5)SLAT(ISHOT)=-SLAT(ISHOT)
  SLNG(ISHOT)=.174532925E-1*(SLNGDG +SLNGMN/60. +SLNGSC/3600.)
  IF(SLNGEW.EQ.W)SLNG(ISHOT)= -SLNG(ISHOT)
  GO TO 4
  10 DO 14 I=1,2
  READ 11,RLAT,RCLNG(1),RDEPTH(1)
  11 FORMAT(2F15.0,F10.0)
  RLAT=RLAT -.33726712E-2*SIN(2.*RLAT) +.5687E-5*SIN(4.*RLAT)
  RCLAT(1)=RLAT
  RCLAT(1+2)=RLAT
  RCLNG(1+2)=RCLNG(1)
  14 RDEPTH(1+2)=RDEPTH(1)
  M=0
  15 READ 12,ISTN,RDAY,ISHOT,JSRC,ISSETUP,ICHAN,RMR,RMN,RSCST,DURMIN,
  1 DURSEC,RSC,IAMP,DBRISE,DBKGD,ATTEN,GZERO,ATZERO
  12 FORMAT(12,5X,F2.0,2X,14,12,14,12,5F2.0,4F3.2,4X,12,2F3.1,F2.0,F3.0
  1 ,F2.0)

```

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```

IF (ISIN.GT.20) GO TO 10
N=0
FUDGE=0.
IF (RSC.GT.RSC(ICHAN)) FUDGE=50.
TIME= 86400.* (IDAY-SDAY(ISHOT)) + 3600.* (IMHR-SHR(ISHOT))
+ 60.* (IMIN-SMN(ISHOT)) + RSC(ICHAN) - SSEC(ISHOT) + FUDGE
RLAT=RLAT(ICHAN)
RLNG=RLNG(ICHAN)
CALL GCD(RLAT,RLNG,SLAT(ISHOT),SLNG(ISHOT),RANGE,EM,EN)

AVLAT= .5*( RLAT+SLAT(ISHOT))
RADIUS=6378388.* (1.998320047 +.1683494E-2*COS(2.*AVLAT))-.3549E-5*
+ COS(4.*AVLAT)
RANGE=RADIUS+RANGE
CHARGE=RANGE/TIME
RCV=RANGE*.001
DT=RSC(1)-RSC(2)
IF (RSC(1).EQ.0..AND.RSC(2).EQ.0.) DT=RSC(3)-RSC(4)
SPL=0.015E+03BKND+ATTEN -GZERO-ATZERO+80.
IDAY=IDAY(ISHOT)+1.
IMIN=SMN(ISHOT) +1.
IMH=SHR(ISHOT) +1.
IF (MOD(N,40).EQ.1) PRINT 20
20 FORMAT(1H)
IF (MOD(N,40).EQ.1) PRINT 22,LABEL
PRINT 24,JSRC,ISTN,ISHOT,IMO(ISHOT), N2(IDAY),N2(IMH),N2(IMIN),
IRK,CUAR,SDEPTH(ISHOT),RDEPTH(ICHAN),DT,SPL
PUNCH 24,JSRC,ISTN,ISHOT,IMO(ISHOT), N2(IDAY),N2(IMH),N2(IMIN),
IRK,CUAR,SDEPTH(ISHOT),RDEPTH(ICHAN),DT,SPL
24 FORMAT( 4I3,1H/,A2,4H/64 ,2I2,F9.2,F9.2,2F6.0,F7.2,F6.0,14X)
GO TO 15
END

```

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## APPENDIX IV

### AVERAGE SOFAR VELOCITY LISTINGS

The following are listings of the output from the sound velocity program described in Section 6 and Appendix III. Average velocities are given for the GM DRL deployable monitoring buoy station for both the Oahu and TI 2376-1b shots. The column headings are self-explanatory (ZSOURCE and ZREC are depths in meters).

#### AVERAGE SOUND VELOCITIES TI ALEUTIAN SHOTS IN GM/DRL BUOY

| SCR<br>No | RC<br>No | Shot<br>No | Date<br>mo dy yr | Source<br>Time | Range<br>km | C Avg<br>m/sec | Z Source<br>m | Z Rec<br>m |
|-----------|----------|------------|------------------|----------------|-------------|----------------|---------------|------------|
| 2         | 11       | 23         | 090264           | 2311           | 4805.93     | 1468.70        | 91.           | 732.       |
| 2         | 11       | 22         | 090464           | 2336           | 4863.44     | 1468.54        | 91.           | 732.       |
| 2         | 11       | 11         | 090764           | 0527           | 4803.48     | 1468.06        | 91.           | 732.       |
| 2         | 11       | 13         | 090764           | 1824           | 4696.37     | 1468.08        | 91.           | 732.       |
| 2         | 11       | 26         | 090764           | 2305           | 4649.46     | 1468.49        | 91.           | 732.       |
| 2         | 11       | 25         | 090864           | 0230           | 4693.80     | 1468.53        | 91.           | 732.       |
| 2         | 11       | 24         | 090864           | 0557           | 4746.58     | 1468.47        | 91.           | 732.       |

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## AVERAGE SOUND VELOCITIES GM/DRL OAHU SHOTS TO GM/DHL HUOY

| SRC NO | RC NO | SHOT NO | DATE    | SOURCE TIME | RANGE KM | C AVG 47SEC | ZSOURCE M | ZREC M |
|--------|-------|---------|---------|-------------|----------|-------------|-----------|--------|
| 1      | 11    | 1       | 9/01/64 | 0801        | 3925.04  | 1481.59     | 720.      | 732.   |
| 1      | 11    | 2       | 9/01/64 | 1000        | 3925.73  | 1477.82     | 720.      | 732.   |
| 1      | 11    | 3       | 9/01/64 | 1600        | 3930.32  | 1480.34     | 649.      | 732.   |
| 1      | 11    | 6       | 9/01/64 | 1800        | 3927.31  | 1480.69     | 732.      | 732.   |
| 1      | 11    | 7       | 9/01/64 | 2003        | 3926.49  | 1480.03     | 707.      | 732.   |
| 1      | 11    | 8       | 9/01/64 | 2201        | 3926.77  | 1480.17     | 676.      | 732.   |
| 1      | 11    | 9       | 9/02/64 | 0002        | 3927.09  | 1479.83     | 947.      | 732.   |
| 1      | 11    | 10      | 9/02/64 | 0500        | 3926.01  | 1479.21     | 711.      | 732.   |
| 1      | 11    | 12      | 9/02/64 | 1100        | 3926.73  | 1479.77     | 872.      | 732.   |
| 1      | 11    | 13      | 9/02/64 | 1303        | 3926.51  | 1479.81     | 801.      | 732.   |
| 1      | 11    | 15      | 9/02/64 | 1700        | 3925.85  | 1479.41     | 771.      | 732.   |
| 1      | 11    | 18      | 9/02/64 | 2302        | 3925.86  | 1479.31     | 750.      | 732.   |
| 1      | 11    | 19      | 9/03/64 | 0102        | 3925.96  | 1479.30     | 803.      | 732.   |
| 1      | 11    | 20      | 9/03/64 | 0200        | 3926.10  | 1479.46     | 841.      | 732.   |
| 1      | 11    | 21      | 9/03/64 | 0300        | 3926.10  | 1479.44     | 850.      | 732.   |
| 1      | 11    | 22      | 9/03/64 | 0904        | 3926.64  | 1479.90     | 881.      | 732.   |
| 1      | 11    | 24      | 9/03/64 | 1304        | 3926.78  | 1478.99     | 863.      | 732.   |
| 1      | 11    | 25      | 9/03/64 | 1500        | 3927.49  | 1479.69     | 854.      | 732.   |
| 1      | 11    | 26      | 9/03/64 | 1700        | 3926.06  | 1479.66     | 845.      | 732.   |
| 1      | 11    | 27      | 9/03/64 | 1800        | 3926.88  | 1479.20     | 858.      | 732.   |
| 1      | 11    | 28      | 9/03/64 | 1900        | 3925.76  | 1479.15     | 820.      | 732.   |
| 1      | 11    | 29      | 9/03/64 | 2000        | 3925.81  | 1479.32     | 761.      | 732.   |
| 1      | 11    | 30      | 9/03/64 | 2101        | 3927.21  | 1479.76     | 730.      | 732.   |
| 1      | 11    | 31      | 9/03/64 | 2200        | 3926.25  | 1479.28     | 860.      | 732.   |
| 1      | 11    | 32      | 9/03/64 | 2300        | 3926.07  | 1479.00     | 860.      | 732.   |
| 1      | 11    | 33      | 9/04/64 | 0000        | 3927.01  | 1479.52     | 802.      | 732.   |
| 1      | 11    | 34      | 9/04/64 | 0100        | 3926.40  | 1478.91     | 774.      | 732.   |
| 1      | 11    | 35      | 9/04/64 | 0200        | 3925.96  | 1478.75     | 802.      | 732.   |
| 1      | 11    | 36      | 9/04/64 | 0304        | 3925.74  | 1478.60     | 788.      | 732.   |
| 1      | 11    | 37      | 9/04/64 | 0400        | 3926.24  | 1477.39     | 766.      | 732.   |
| 1      | 11    | 38      | 9/04/64 | 0500        | 3926.29  | 1478.19     | 817.      | 732.   |
| 1      | 11    | 39      | 9/04/64 | 0604        | 3930.24  | 1479.40     | 831.      | 732.   |
| 1      | 11    | 40      | 9/04/64 | 0702        | 3926.49  | 1479.07     | 729.      | 732.   |
| 1      | 11    | 41      | 9/04/64 | 0801        | 3925.57  | 1479.01     | 883.      | 732.   |
| 1      | 11    | 42      | 9/04/64 | 0900        | 3925.69  | 1478.87     | 841.      | 732.   |
| 1      | 11    | 43      | 9/04/64 | 1003        | 3925.98  | 1479.21     | 773.      | 732.   |
| 1      | 11    | 44      | 9/04/64 | 1701        | 3926.37  | 1479.79     | 801.      | 732.   |
| 1      | 11    | 45      | 9/04/64 | 1801        | 3924.60  | 1479.07     | 831.      | 732.   |
| 1      | 11    | 46      | 9/04/64 | 1900        | 3925.57  | 1479.21     | 704.      | 732.   |
| 1      | 11    | 47      | 9/04/64 | 2000        | 3925.23  | 1478.95     | 589.      | 732.   |
| 1      | 11    | 48      | 9/04/64 | 2101        | 3926.04  | 1479.46     | 586.      | 732.   |
| 1      | 11    | 49      | 9/04/64 | 2200        | 3924.78  | 1478.91     | 831.      | 732.   |
| 1      | 11    | 50      | 9/05/64 | 0103        | 3925.50  | 1478.33     | 766.      | 732.   |
| 1      | 11    | 51      | 9/05/64 | 0300        | 3926.17  | 1478.94     | 784.      | 732.   |
| 1      | 11    | 52      | 9/05/64 | 0400        | 3925.52  | 1478.78     | 659.      | 732.   |
| 1      | 11    | 53      | 9/05/64 | 0502        | 3925.13  | 1478.70     | 624.      | 732.   |
| 1      | 11    | 54      | 9/05/64 | 0600        | 3925.79  | 1479.30     | 663.      | 732.   |
| 1      | 11    | 55      | 9/05/64 | 0700        | 3925.52  | 1479.06     | 591.      | 732.   |
| 1      | 11    | 56      | 9/05/64 | 1200        | 3926.31  | 1479.01     | 667.      | 732.   |
| 1      | 11    | 60      | 9/05/64 | 1600        | 3926.61  | 1478.91     | 615.      | 732.   |

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## APPENDIX V

### SOURCE LOCATION PROGRAM

The following is a listing of the GM DRL source location program configured especially for the University of Hawaii MILE data format. The coding is an IBM 7040 Fortran IV, and the program was run on a 7040 with a real-time storage clock. The program is described in greater detail in Section 6.

```

C PROGRAM TO COMPUTE SOURCE LOCATION OF UNDERWATER ACOUSTIC EVENTS
C BY LEAST SQUARES CRITERIA
C MW MCLENNAN JAN 1965
  DIMENSION RLAT(99),RLNG(99),RCAV(99),SINMTA(25),COSMTA(25),TAR(25)
  1 SLAT(25),SLNG(25),SCAV(25),D(25),CHAD(25),IDAY(25),IMO(25)
  2 INSTN(25),RANGE(25)
  EXTERNAL IBCLK
  REAL N
  GOVT(Y)=Y+.33726712E-2*SIN(2.*Y)-.5687E-5*SIN(4.*Y)
  GOCN(Y)=Y-.33726712E-2*SIN(2.*Y)+.5687E-5*SIN(4.*Y)
  ITIME(T)=4096*MOD(INT(T/60.),10)+252144*MOD(INT(T/600.),6)
  1 +16777216*MOD(INT(T/3600.),10)+1073741824*INT(T/36000.)
  HAD(Y)=6378388.*(1.998320047+.1683494E-2*COS(2.*Y)-.3549E-5*COS(4.*
  1 Y))
  READ 2,N,S,E,W
  2 FORMAT(4A1)
C INPUT STATION DATA
  4 READ 5,ISTN,RLAT(ISTN),RLNG(ISTN),RCAV(ISTN)
  5 FORMAT(12,F13.8,F15.8,F10.2)
  IF(ISTN,EQ,99)GO TO 10
  RLAT(ISTN)=SIGN(GOCN(ABS(RLAT(ISTN))),RLAT(ISTN))
  GO TO 4
C INPUT TRIAL PARAMETERS
  10 READ 12,YZERO,XZERO
  12 FORMAT(2F10.2)
  XZERO=.0174533*XZERO
  YZERO=.0174533*YZERO
  GOTIME=1ABS(1BCLK)
C INPUT STATION ARRIVAL TIMES
  1=0
  15 1=1+1
  17 FORMAT(12,6X,12,5X,12,4X,12,13,2X,12,3X,F3.0,2X,F5.3,9X,12)
  READ 17,JSHOT,IDAY(1),IMO(1),IYR,IHR,IMN,TSC,TFACT,ISTN
  IF(JSHOT,NE,1SHOT)GO TO 20

```

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```

14 SLAT(1)=PLAT(1STN)
   SLNG(1)=PLNG(1STN)
   SCAV(1)=RCAL(1STN)
   NSTN(1)=1STN
   TAR(1)= 3600.*FLOAT(1HR)+60.*FLOAT(1MN)+TSC*TFAC+2/6400.*FLOAT(
1 IDAY(1)-IDAY(1))
   ISHOT=JSHOT
   GO TO 15
22 IF(1.57.1)GO TO 18
   IMAX=1-1
   X=XZERO
   Y=YZERO
   T=TAR(1)-1689.

C START ITERATION
COMPUTE COEFFICIENTS
   ITNO=0
25 ITNO=ITNO+1
   DO 32 I=1,IMAX
     CALL GCD(SLAT(1),SLNG(1),Y,X,RANGE(1),SINBTA(1),COSBTA(1))
     AVLAT=.5*(Y+SLAT(1))
     CRAD(1)=SCAV(1)/RAD(AVLAT)
30 D(1)=CRAD(1)*(TAR(1)-T)-RANGE(1)
     CALL LSTSQJ(SINBTA,COSBTA,CRAD,D,DX,DY,DT,RES,IMAX)
     X=X-DX
     Y=Y-DY
     T=T+DT
     Y=ABS(AMOD(1.5707963-Y,6.2831853))
     IF(Y.GT.3.1415927)Y=6.2831853-Y
     Y=1.5707963-Y
     X=AMOD(X,6.2831853)
     IF(ABS(X).GT.3.1415927)X=SIGN(6.2831853-ABS(X),-X)
     IF(ITNO.GT.29)GO TO 32
     IF(ABS(DX).GT..158E-5.OR. ABS(DY).GT.158E-5)GO TO 25

C OUTPUT RESULTS
32 PRINT 35,ISHOT
35 FORMAT(1H1, 41HLEAST SQUARES SOURCE LOCATION OF T.1,SHOT,13 //
127H ARRIVAL TIMES AT STATIONS /40H STATION DATE GCT
2 RESIDUAL /39H NUMBER MO DY YR HRMN SEC METERS / )
   DO 38 I=1,IMAX
     RESOUT=6371000.*D(1)
     JTIME=TIME(TAR(1))
     SEC=AMOD(TAR(1),60.)
39 PRINT 36,NSTN(1),INO(1),IDAY(1),1YR,JTIME,SEC,RESOUT
36 FORMAT(2I6,2(1H/,12),2X,A4,F6.2, F8.0)
   PLATNS=N
   IF(Y.LT.0.)PLATNS=S
   PLAT=57.2957795*GDDT(ABS(Y))
   ILATDG=PLAT
   ILATMN= 60.*AMOD(PLAT,1.)

```

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```

      ILATSC= AMOD(3600.*PLAT,60.)
      PLNGEW=F
      IF (Y.LT.0.) PLNGEW=W
      PLNGE= 57.2957795*ARS(X)
      ILNGDG=PLNG
      ILNGMN=60.*AMOD(PLNG,1.)
      ILNGSC=AMOD(3600.*PLNG,60.)
      JTIME=JTIME(T)
      SEC= AMOD(T,60.)
      IC=2
      RESOUT=6371000.*RES
      PRINT 40
40  FORMAT(///61H SHOT   DATE       GCT       LATITUDE  LONGITUDE  RMS
      1     NO.   /
      2           64H      MO DY YR HRMN SEC    DG MN SC    DEG MN SC    RES
      4  ITERATIONS  )
      PRINT 41,ISHOT,IMO(1),IDAY(1),IYR,JTIME,SEC,ILATDG,ILATMN,ILATSC,
      1  PLATNS,ILNGDG,ILNGMN,ILNGSC,PLNGEW,RESOUT,ITNO
41  FORMAT(2H 2,213,2(1H/,12),1X,A4,F6,2,14,213,A1,15,213,A1,F6,0,15)
      PUNCH 42,ISHOT,IMO(1),IDAY(1),IYR,JTIME,SEC,ILATDG,ILATMN,ILATSC,
      1  PLATNS,ILNGDG,ILNGMN,ILNGSC,PLNGEW,RESOUT
42  FORMAT(2H 2,213,2(1H/,12),1X,A4,F6,2,14,213,A1,15,213,A1,F6,0,26X)
      TLAPSE=(FLOAT(1ABS(1BCLK)) -GOTIME)/60.
      GOTIME=1ABS(1BCLK)
      PRINT 45,TLAPSE
45  FORMAT(///18H COMPUTATION TIME= ,F7.3, 4H SEC )
C SET UP FOR NEXT SET
      IDAY(1)=IDAY(IMAX+1)
      IMO(1)=IMO(IMAX+1)
      I=1
      GO TO 1
      END

```

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## APPENDIX VI

### SOURCE LOCATIONS OF 248-lb SHOTS

The following is a tabulation of probable source locations for the TI 248-lb shots. Three sets of figures are given for each shot.

- a) The output of the GM DRL program
- b) The radar-derived position of the plane at the time of drop
- c) The output of the University of Hawaii epicenter location program

Lines a) and c) differ only in that the University of Hawaii program used only the MILS data, while the GM program used additional data from two West Coast stations.

In the column marked Res-RMS, the GM station residual is expressed as rms meters, whereas the University of Hawaii residual is apparently expressed as the mean of the absolute value of the residual in seconds. There is no residual expressed for the radar fixes. Since these source cards are in the same format as the TI source logs, the extra three numbers refer respectively to shot depth (meters), charge weight (pounds), and local water depth (meters).

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SOURCE POSITIONS OF T-1. 248-LB ALEUTIAN SHOTS AS COMPUTED BY

1. GM/DRL PROGRAM USING U.O.F H. DATA PLUS WEST COAST HYDROPHONES  
 2. NAVIGATIONAL RADAR, AS REPORTED IN U.S.C+GS MEMO DATED 1 OCT 1964  
 3. U.O.F HAWAII PROGRAM USING MILS HYDROPHONE DATA

| SHOT | MO      | DY | YR         | HRMN  | SEC | DEG       | MN | SC | DEG        | MN | SC | RES    |      |      |  |  |
|------|---------|----|------------|-------|-----|-----------|----|----|------------|----|----|--------|------|------|--|--|
|      | DATE    |    | GCT        |       |     | LATITUDE  |    |    | LONGITUDE  |    |    | RMS    |      |      |  |  |
| 2 65 | 9/17/64 |    | 2259       | 55.74 |     | 51 27 22N |    |    | 176 39 12W |    |    | 2154.  |      |      |  |  |
| 2 65 | 9/17/64 |    | 2259       | 51.00 |     | 51 35 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 183  |  |  |
|      |         |    | 2259       | 54    |     | 51.5 N    |    |    | 175.6 W    |    |    | 1.3    |      |      |  |  |
| 2 66 | 9/17/64 |    | 2315       | 1.62  |     | 51 13 32N |    |    | 176 38 13W |    |    | 5061.  |      |      |  |  |
| 2 66 | 9/17/64 |    | 2314       | 59.00 |     | 51 25 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 1428 |  |  |
|      |         |    | 2314       | 54    |     | 51.3 N    |    |    | 176.6 W    |    |    | 3.5    |      |      |  |  |
| 2 67 | 9/17/64 |    | 2331       | 41.85 |     | 51 7 27N  |    |    | 176 37 52W |    |    | 4268.  |      |      |  |  |
| 2 67 | 9/17/64 |    | 2331       | 34.00 |     | 51 15 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 3480 |  |  |
|      |         |    | 2331       | 36    |     | 51.2 N    |    |    | 176.6 W    |    |    | 3.0    |      |      |  |  |
| 2 68 | 9/18/64 |    | -014-33.20 |       |     | 50 38 29N |    |    | 176 36 49W |    |    | 4057.  |      |      |  |  |
| 2 68 | 9/17/64 |    | 2345       | 26.00 |     | 51 05 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 3850 |  |  |
|      |         |    | 2345       | 28    |     | 51.0 N    |    |    | 176.6 W    |    |    | 2.9    |      |      |  |  |
| 2 69 | 9/18/64 |    | 0030       | 27.16 |     | 50 59 3N  |    |    | 176 31 50W |    |    | 7039.  |      |      |  |  |
| 2 69 | 9/18/64 |    | 0030       | 37.00 |     | 50 55 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 3380 |  |  |
|      |         |    | 0 30       | 29    |     | 51.0 N    |    |    | 176.5 W    |    |    | 2.7    |      |      |  |  |
| 2 70 | 9/18/64 |    | 0044       | 39.68 |     | 50 49 2N  |    |    | 176 35 23W |    |    | 5192.  |      |      |  |  |
| 2 70 | 9/18/64 |    | 0044       | 45.00 |     | 50 45 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 4395 |  |  |
|      |         |    | 0044       | 42    |     | 50.8 N    |    |    | 176.6 W    |    |    | 2.2    |      |      |  |  |
| 2 71 | 9/18/64 |    | 0100       | 5.31  |     | 50 48 11N |    |    | 176 35 0W  |    |    | 11137. |      |      |  |  |
| 2 71 | 9/18/64 |    | 0100       | 13.00 |     | 50 35 00N |    |    | 176 38 24W |    |    | 38.    | 248. | 6220 |  |  |
|      |         |    | 0100       | 15    |     | 50.7 N    |    |    | 176.6 W    |    |    | 2.9    |      |      |  |  |
| 2 72 | 9/18/64 |    | 0115       | 14.08 |     | 50 28 39N |    |    | 176 36 45W |    |    | 3926.  |      |      |  |  |
| 2 72 | 9/18/64 |    | 0115       | 19.00 |     | 50 22 51N |    |    | 176 40 00W |    |    | 38.    | 248. | 6960 |  |  |
|      |         |    | 0115       | 20    |     | 50.4 N    |    |    | 176.6 W    |    |    | 2.6    |      |      |  |  |
| 2 73 | 9/20/64 |    | 2159       | 57.59 |     | 51 53 22N |    |    | 174 46 11W |    |    | 2813.  |      |      |  |  |
| 2 73 | 9/20/64 |    | 2159       | 58.00 |     | 51 52 27N |    |    | 174 43 18W |    |    | 38.    | 248. | 156  |  |  |
|      |         |    | 2159       | 56    |     | 51.9 N    |    |    | 174.8 W    |    |    | 1.1    |      |      |  |  |

GM DEFENSE RESEARCH LABORATORIES & GENERAL MOTORS CORPORATION

TR65-28

SOURCE POSITIONS OF T-1. 248-LB ALLUTIAN SHOTS AS COMPUTED BY

1. GMDRL PROGRAM USING U.O.F. H. DATA PLUS WEST COAST HYDROPHONES
2. NAVIGATIONAL RADAR, AS REPORTED IN U.S.C+GS MEMO DATED 1 OCT 1964
3. U.O.F. HAWAII PROGRAM USING MILS HYDROPHONE DATA

| SHOT | MO      | DAY | YR | HRMN       | SEC   | DG       | MN | SC  | DEG       | MN | SC  | RES   |      |      |  |  |
|------|---------|-----|----|------------|-------|----------|----|-----|-----------|----|-----|-------|------|------|--|--|
|      | DATE    |     |    | GCT        |       | LATITUDE |    |     | LONGITUDE |    |     | RMS   |      |      |  |  |
| 2 74 | 9/20/64 |     |    | 2150       | 14.99 | 51       | 55 | 59N | 175       | 26 | 37W | 1718. |      |      |  |  |
| 2 74 | 9/20/64 |     |    | 2150       | 18.00 | 51       | 52 | 54N | 175       | 23 | 24W | 38.   | 248. | 145  |  |  |
|      |         |     |    | 2150       | 08    | 52.0     |    | N   | 175.4     |    | W   | 1.3   |      |      |  |  |
| 2 75 | 9/20/64 |     |    | 2236       | 30.32 | 51       | 41 | 23N | 175       | 55 | 39W | 4981. |      |      |  |  |
| 2 75 | 9/20/64 |     |    | 2236       | 25.00 | 51       | 45 | 12N | 175       | 55 | 00W | 38.   | 248. | 180  |  |  |
|      |         |     |    | 2236       | 33    | 51.7     |    | N   | 175.9     |    | W   | 1.3   |      |      |  |  |
| 2 76 | 9/20/64 |     |    | 2132       | 47.07 | 51       | 36 | 28N | 176       | 14 | 17W | 3134. |      |      |  |  |
| 2 76 | 9/20/64 |     |    | 2132       | 43.00 | 51       | 40 | 30N | 176       | 15 | 24W | 38.   | 248. | 165  |  |  |
|      |         |     |    | 2132       | 47    | 51.6     |    | N   | 176.2     |    | W   | 1.3   |      |      |  |  |
| 2 77 | 9/20/64 |     |    | 2046       | 55.66 | 51       | 31 | 7N  | 177       | 13 | 14W | 1392. |      |      |  |  |
| 2 77 | 9/20/64 |     |    | 2046       | 46.00 | 51       | 40 | 30N | 177       | 04 | 00W | 38.   | 248. | 120  |  |  |
|      |         |     |    | 2046       | 57    | 51.5     |    | N   | 177.2     |    | W   | 1.1   |      |      |  |  |
| 2 78 | 9/20/64 |     |    | 2032       | 41.59 | 51       | 28 | 46N | 177       | 28 | 41W | 1070. |      |      |  |  |
| 2 78 | 9/20/64 |     |    | 2032       | 30.00 | 51       | 40 | 12N | 177       | 24 | 24W | 38.   | 248. | 137  |  |  |
|      |         |     |    | 2032       | 44    | 51.4     |    | N   | 177.5     |    | W   | 1.1   |      |      |  |  |
| 2 79 | 9/20/64 |     |    | 2022       | 34.17 | 51       | 39 | 31N | 177       | 53 | 49W | 3469. |      |      |  |  |
| 2 79 | 9/20/64 |     |    | 2022       | 38.00 | 51       | 35 | 00N | 177       | 47 | 48W | 38.   | 248. | 147  |  |  |
|      |         |     |    | 2023       | 08    | 51.2     |    | N   | 177.9     |    | W   | 0.9   |      |      |  |  |
| 2 80 | 9/20/64 |     |    | 1943       | 56.75 | 51       | 39 | 43N | 178       | 18 | 17W | 8654. |      |      |  |  |
| 2 80 | 9/20/64 |     |    | 1943       | 59.00 | 51       | 33 | 42N | 178       | 15 | 21W | 38.   | 248. | 210  |  |  |
|      |         |     |    | 1944       | 07    | 51.5     |    | N   | 178.3     |    | W   | 4.8   |      |      |  |  |
| 2 81 | 9/20/64 |     |    | 2323       | 19.35 | 51       | 29 | 59N | 178       | 46 | 18W | 5619. |      |      |  |  |
| 2 81 | 9/20/64 |     |    | 2323       | 07.00 | 51       | 28 | 42N | 178       | 37 | 21W | 38.   | 248. | 320  |  |  |
|      |         |     |    | 2323       | 25    | 51.4     |    | N   | 178.7     |    | W   | 2.7   |      |      |  |  |
| 2 82 | 9/21/64 |     |    | -007-29.44 |       | 51       | 6  | 49N | 179       | 22 | 16W | 2571. |      |      |  |  |
| 2 82 | 9/20/64 |     |    | 2352       | 21.00 | 51       | 12 | 24N | 179       | 15 | 00W | 38.   | 248. | 1815 |  |  |
|      |         |     |    | 2352       | 26    | 51.2     |    | N   | 179.4     |    | W   | 1.8   |      |      |  |  |
| 2 83 | 9/21/64 |     |    | 0018       | 25.33 | 50       | 56 | 3N  | 179       | 35 | 20E | 2461. |      |      |  |  |
| 2 83 | 9/21/64 |     |    | 0018       | 07.00 | 51       | 12 | 06N | 179       | 29 | 24E | 38.   | 248. | 1095 |  |  |
|      |         |     |    | 0018       | 22    | 51.0     |    | N   | 179.6     |    | E   | 1.8   |      |      |  |  |
| 2 84 | 9/21/64 |     |    | 0040       | 57.33 | 51       | 27 | 21N | 178       | 57 | 10E | 625.  |      |      |  |  |
| 2 84 | 9/21/64 |     |    | 0041       | 02.00 | 51       | 19 | 54N | 178       | 59 | 00E | 38.   | 248. | 210  |  |  |
|      |         |     |    | 0040       | 55    | 51.5     |    | N   | 178.9     |    | E   | 0.5   |      |      |  |  |
| 2 16 | 9/21/64 |     |    | 0105       | 19.69 | 50       | 52 | 24N | 179       | 13 | 58E | 3195. |      |      |  |  |
| 2 16 | 9/21/64 |     |    | 0105       | 10.00 | 50       | 59 | 30N | 179       | 10 | 36E | 38.   | 248. | 3300 |  |  |
|      |         |     |    | 0105       | 20    | 50.9     |    | N   | 179.3     |    | E   | 2.5   |      |      |  |  |

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